A Framework for Evaluating In-vehicle Applications Regarding Safety

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Driver distraction is a serious and growing hazard to road safety. With the rapid introduction of the new information, communication, and entertainment technologies, this problem is becoming more threatening in the coming years. For instance, drivers who use mobile phones while driving are more likely to be involved in the car crash than those who do not.

However, using technologies such as mobile phones and navigation systems in a vehicle can have different personal, social, practical, and psychological advantages which outweigh the risk. Therefore, there are number of metrics and methods for evaluating in-vehicle technologies, their services, applications, and functionalities to improve and make them safer.

The purpose of this thesis was to investigate and develop a new framework which consists of a safety evaluation library and server for evaluating in-vehicle applications with safety consideration. By the use of the framework, Original Equipment Manufacturers (OEMs) and third-party developers can get safety feedback from their in-vehicle applications in the real driving situation. For the safety analysis, different metrics were investigated. Due to the time restriction and based on the possible information that could be collected from an application and a vehicle, four metrics were used in the safety analysis including, total task time, number of interactions, speed, and completed task rate.

In addition, the framework was deployed and tested by two case-study applications and some interesting results were discovered. Moreover, it was found out using the safety library by third-party developers is quite easy, which is one of the most important factors in the usability area.

Key words and terms: driver distraction, measuring distraction while driving, safety, metrics

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1 INTRODUCTION

Driver distraction is not a new traffic safety problem, although recently it has become a critical issue for drivers and designers. This is mainly because of the fast development of mobile technology and services such as cellphone, navigation system and their use in the vehicles while driving. However, most of these services and functionalities are not designed for drivers' use while driving since it might lead to a great distraction and car crash.

According to the US National Highway Traffic Safety Administration (NHTSA), in 2008, nearly 11% of drivers (approximately one million individuals) used a mobile device at some time. Additionally, 35-50% of drivers admit that they use cell phone while driving. A study in 2014 also estimated the odds ratios and corresponding confidence intervals for a crash or near-crash associated with each secondary task. Among novice drivers, dialing or reaching for a cell phone, texting, reaching for an object other than a cell phone, looking at a roadside object such as a vehicle in a previous crash, and eating were all associated with a significantly increased risk of a crash or near-crash. Among experienced drivers, only cell-phone dialing was associated with an increased risk. [Klauer et al., 2014]

Another study [White et al., 2008] in Australia in 2006 shows that 43 % of mobile users used their mobile phone while driving to answer calls, 24 % to make calls, 16% to read, and 7% to send text messages. Thus, despite the fact that using mobile phone while driving will distract drivers and increase a risk to driver safety, many drivers still engage in this behavior.

Lissy [2000] conducted a series of exploratory focus group to identify the type of benefits of using a cellular phone while driving and divided them in five groups:

- *Personal benefits*: use of a cellular phone can help drivers prevent unnecessary trips and reduce overall time on the road because of more effective communication with their families, friends and business people. In this case, travel time not only is time-saving issue but also reduces traffic crashes and injuries. A cellular phone also gives a driver a chance to notify colleagues when s/he is running late and this makes the driver not to driver fast to reach the destination and decreases car crashes caused by high speed.
- *Family benefits*: using a cellular phone while driving allow parents to leave work earlier, make their call on their way home, and thus spend more time with their family.

- *Social network benefits*: making calls to friends in order to socialize is one of the benefits of using a cellular phone when a driver gets stuck in the traffic jam.
- *Business benefit*: since time plays an important role in the business, using a cellular phone can help businessman makes most out of the time by changing idle time to productive one. It also makes it possible to contact workers while driving which improves responsiveness to issue that arise with her/his client or co-workers. Thus it improves relationship with client or help anxious co-worker to find answer to a question before an important meeting with client.
- *Community benefit*: reporting emergency incidents by drivers using cellular phones makes it easier for emergency personnel handles the situation. For example, drivers with cellular phones report roadside accidents immediately after the occurrence, can improves the response time of emergency services personnel.

Based on personal, social, practical, and psychological benefits from using mobile phone that are mentioned above, it is noticeable that mobile phone users believe that advantages outweigh the risks. Regarding this, it can be expected that benefits of mobile phone use could affect the decision to use of mobile phone as well as other mobile services such as applications while driving [White et al., 2008].

Therefore, instead of banning use of mobile and in-vehicle technology, their services, and functionalities while driving, automotive industry must overcome safety and distraction issue.

1.1 Problem and Goal

In the 21st century, we have been experiencing significant changes in the driver-vehicle interfaces and implementing more complicated technologies in the car.

Because of an enormous growth in on-board/off-board electronic functionality, the drivers will be overwhelmed by all these technologies in the vehicle. The result might be that the drivers do not use a particular system which can even make the driving easier. Or in the worst case, interacting with in-vehicle functionalities makes the driver not to be able to control the vehicle in the safe manner. According to the recent researches [NHTSA, 2012; ERTRAC, 2011; NHTSA, 2010; Kircher et al., 2011] lack of attention and distraction are the main reasons of the car accidents on the road, so systems that may contribute to this problem must be carefully designed [Burnett and Porter, 2001].

So far safety plays an important role in in-vehicle applications since the use of these applications distracts the driver from the important task of driving. The problem addressed in this thesis, is how to evaluate and get feedback from in-vehicle applications to measure distraction in the real driving environment.

The goal of this thesis is to design a framework that embeds into in-vehicle applications and automatically collects user interface and vehicle data as users interact with the applications. Then, the collected data will be uploaded in the server and used for the safety analysis. The developers can receive these feedbacks (e.g. a specific task takes too much time to complete; some tasks never get finished; some tasks get too much attention of a driver) and improve the application. After designing the framework, we implement it on Android platform and evaluate the framework with a real deployed Android application. Furthermore, this framework is applied and tested by two case study projects which are in-vehicle applications.

1.2 Thesis Outline

This work is structured in 6 major chapters: Introduction is the present chapter which contains problem and goal of this thesis. Chapter 2, Background theory, focuses on literature review about the definition of driver distraction as well as technology-based sources of distraction inside the vehicle. In addition, different driver safety guidelines and standards are reviewed. In Chapter 3, five different methods of measuring driver distraction, advantages and disadvantages are reviewed. Chapter 4 covers application and vehicle metrics regarding measuring the distraction based on the literature review. It also discusses the methodology of this thesis using design science approach. Chapter 5 presents the actual implementation of the framework. It starts with an overview of the framework, continues with a comparison with other methods discussed in Chapter 3 and finishes with two case study in-vehicle applications. Finally, chapter 6 provides conclusions and future works by summarizing the findings and discussing the recommendations for further work.

2 BACKGROUNG THEORY

Driving is considered as a complex task in everyday people's life which requires a significant degree of attention and concentration on the part of drivers. However, many drivers engage in various other activities while driving such as listening to radio, eating or talking to passengers. This behavior is becoming more and more common with the introduction of technologies such as navigation system and wireless communication such as mobile phones. Regarding this, many researches have been conducted to investigate about driver distraction and its effect on driving performance. This chapter starts with discussing different definitions of driver distraction and technology-based source of distraction following by reviewing of driver safety guideline and standards.

2.1 Driver Distraction

Driver distraction happens when driver's attention is diverted from the driving task because of an event or object which the driver cannot perform driving task in a safe way. Table 1 shows different definitions of driver distraction in literature which collected by Tasca [2005]. However, all definitions have the same concept which says distraction can get the driver's attention away from the primary task of controlling the vehicle.

Based on NHTSA, driver distraction are categorized in four groups, namely visual, auditory, biomechanical, and cognitive distraction [Ranney et al., 2001]:

- Visual distraction: visual distraction itself consists of three types. The first type happens when some objects block the driver's visual such as dark window tints or car's windscreen that can stop the driver from recognizing object and react properly to hazard on the road. The second form occurs when a driver does not look at the road and cannot focus on driving task because some other visual target gets his/her attention for an extended period of time like an in-car route navigation system. The third and the most interesting type is a loss of attention in the driving situation and usually referred to as "looked, but did not see" and prevent the driver to recognize hazard on the road [Ito et al., 2001].
- Auditory distraction: when a driver constantly focus on sounds or auditory signal such as responding to a ringing cell phone rather than on the road, auditory distraction happens [Ranney et al., 2001].

- Biomechanical distraction: it occurs when a driver removes one or both hands from the steering wheel in order to do other activities such as manipulating an object [Tchankue et al., 2011].
- Cognitive distraction: this type of distraction can get the driver's mental attention away from the driving task. It can prevent the drivers from being able to navigate through the road and their reaction time is reduced [NHTSA, 2012]. One of the most common example of the cognitive distraction is talking on the phone while driving.

Source	Definition
Ranney et al., 2000	Driver distraction may be characterized as any activity that takes a driver's attention away from the task of driving. Any distraction from rolling down a window to using a cell phone can contribute to a crash. Four distinct categories of distraction: - Visual (e.g., looking away from roadway) - Auditory (e.g., responding to ringing cell phone) - Biomechanical (e.g., adjusting CD player) - Cognitive (e.g., lost in thought).
Stutts et al., 2001	Distraction occurs when a driver is delayed in recognition of information needed to safely accomplish the driving task because some event, activity, object or person (both inside and outside the vehicle) compelled or tended to induce the driver's shifting attention away from the driving task.
Beirness et al., 2002	Need to distinguish distraction from inattention. Distracted driving is part of the broader category of driver inattention. Presence of a triggering event or activity distinguishes driver distraction as a subcategory of driver inattention.
Green, 2004	Driver distraction is not a scientifically defined concept in the human factors literature. As used by the layperson, it refers to drawing attention to different object, direction or task. A distraction grabs and retains the driver's attention.
Tasca, 2005	A voluntary or involuntary diversion of attention from primary driving tasks not related to impairment (from alcohol/drugs, fatigue or a medical condition) Diversion occurs because the driver is: ● Performing an additional task (or tasks) or ● Temporarily focusing on an object, event or person not related to primary driving tasks. Diversion reduces a driver's situational awareness, decision-making and/or performance resulting in any of the following outcomes: ● Collision ● Near-miss ● Corrective action by the driver and/or another road user.

Table 1. Definition of driver distraction

It should be noted that all types of distraction that are mentioned above can happen at the same time. Take an example of changing the music from in-vehicle CD player system while driving:

Visual distraction: it causes by looking at the CD player system.

Auditory distraction: it causes when a driver listens to the music.

Physically distraction: it causes by removing at least one hand from the steering wheel and manipulating the in-vehicle CD player system (e.g. changing a song or manipulating the volume).

Cognitive distraction: it causes by focusing on the music rather than on driving task.

Moreover, Stutts et al. [2001] states thirteen sources of distraction based on NHTSA:

1. eating or drinking,
2. outside person, object or event,
3. adjusting radio, cassette, or CD,
4. other occupants in vehicle,
5. moving object in vehicle,
6. smoking related,
7. talking or listening on mobile phone,
8. dialing mobile phone,
9. using device or object brought into vehicle,
10. using device or controls integral to vehicle,
11. adjusting climate controls,
12. other distraction, and
13. unknown distraction.

In general, sources of distraction can be categorized into two main groups: technology-based distracters (e.g., mobile phones and route navigation systems) and non-technology based distracters (e.g. eating, drinking, and smoking). Our focus in this studies is on technology-based distracters.

2.2 Technology-Based Sources of Distraction in Vehicle

Although most of the studies in distraction area has been focused more on using mobile phone while driving, many other technologies has been used in the vehicle. They consist of “fixed” vehicle system like those one that are fitted by factory or retrofitted and “nomadic” (portable) devices that provide various functionalities such as entertainment, provision of information, and communication such as mobile phone or in-vehicle navigation devices or applications. However, many of these devices and technologies are not designed to be used in vehicle while driving. It should be considered that even in the same type of technologies, there may be significant differences between products. In addition, system functionalities such as design of the human-machine interface (HMI) vary between devices which have a considerable impact on distraction and the amount of time and effort needed to interact with the device. In this section, the existing literature regarding the effect of some technology-based distractions on driving performance and road safety is examined.

2.2.1 Mobile Phones

There has been a rapid growth in using of mobile phone over the past decade in all parts of the world. Figure 1 shows the steady growth in the number of mobile phone subscriptions worldwide. As it can be seen form Figure 1, 96.2 per 100 inhabitants had the mobile cellular telephone subscription at the end of 2013.

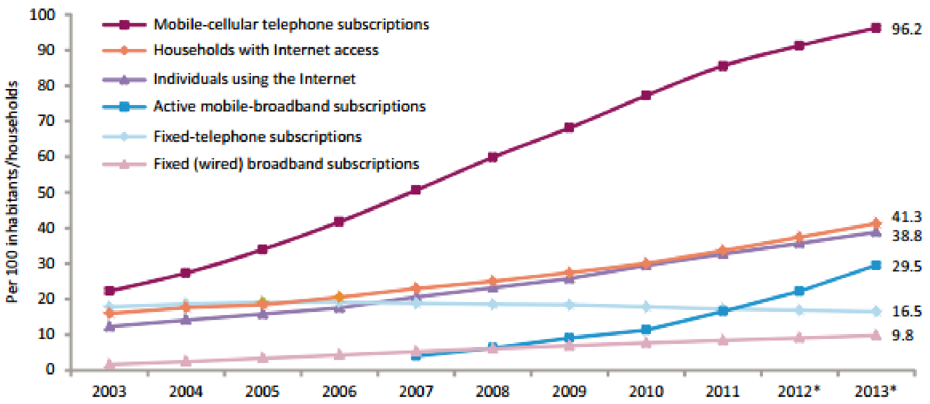


Figure 1. Global Information and Communication Technology development, 2003-2013 [International Organization for Standardization, 2013].

As number of mobile phone owners increase quickly around the world, the use of mobile phones in vehicles is also rising rapidly. For instance, in the United States and Australia, 60-70 % of drivers use a mobile phone at least sometimes while driving [Klauer et al., 2006]. Therefore, mobile phone while driving has got a significant amount of research attention. Most research studies show that there is an important relationship between mobile phone use while driving and car crash risk [Lam, 2002]. Nevertheless, there are a lot of variables involved in measuring the effects of mobile phone use on driving performance such as level of complexity associated with mobile phone conversation and there is little information in literature about how exactly these variables can affect specific aspect of driving performance [Christopher et al., 2001].

Drivers can be distracted visually, physically, and cognitively by using mobile phone while driving. Physical and visual distraction is mostly happened when working with a hand-held phone, but can also occur when using a hands-free phone. In both case of using hands-free and hand-held phone, drivers are required to look way from the road and their hands off the wheel to reach for the phone and either dialing a number or answering an incoming call. Auditory distraction, in the form of responding to a ringing phone, can also happen, although the duration of this distraction is likely to be shorter than visual and physical distraction. Moreover, handheld phones have the additional physical distraction of requiring the driver to drive one handed while holding the phone during a conversation [World Health Organization, 2011].

Hand-held Mobile Phone. A lot of studies have examined the effect of operating a hand-held phone on driving performance. In one study, Reed and Green [1999] examined the impact of using a hand-held mobile phone on driving performance in a fixed-based driving simulator and on real roads. Six women and six men drivers drove along a freeway route in an instrumented vehicle while occasionally making calls on a hand-held mobile phone. The same participants then drove a similar route in a driving simulator while also making phone calls. The main focus of the study was to determine if the results found in the driving simulator corresponded to results found in an on-road instrumented vehicle. Nonetheless, it provides important insights into the degrading effects of mobile phone use on driving. The result showed that use of the mobile phone reduced driving performance associated with dialing a car phone both on the road and in the driving simulator.

Hand-Free Mobile Phones. As the use of in-vehicle technology becomes more popular and mobile phones markets expand rapidly, hands-free phones are being developed to decrease physical distraction associated with mobile phone use as well as other aids, such as voice activation and speed dialing. Hands-free phone devices have less impact on driving performance in comparison with hand-held mobile phone and it has become the subject of many investigations. While hand-held phones can physically distract drivers by holding the phone to the ear, a number of studies indicate that using hands-free phones also has negative effect on different aspects of driving performance such as an increased reaction time, which are similar to using a hand-held phone.

According to one research in Canada [Harbluk et al., 2002], using hands-free phones while driving has been shown to lead to reduced time looking and checking instruments in the car and negatively effect on vehicle control. This study revealed that hands-free phones are not safer to use than hand-held phones in terms of driving performance. Therefore, using a hands-free mobile phone may be as likely to cause a car crash as using a hand-held mobile phone since it is the cognitive distraction that has the most impact upon driving.

It is important to note that drivers may reduce their average driving speed while using a hand-held phone in order to reduce their car crash risk. However, MC Cartt et al. [2006] found that drivers using hands-free phones are less likely to show such that behavior compared with those who drive and use hand-held phones. This may be because the physical presence of a hand-held phone acts as a reminder to the driver that the potential safety threat may occur by the use of the phone.

Text Messaging. The effects of sending or receiving text messages on driving behavior are very important. While very little research has been conducted in this area, existing studies (mostly experimental) reveal that sending a text message is considered to be the most distracting activity to perform while driving. These studies suggests that text messaging while driving leads to increased cognitive distraction in order to write text messages, physical distraction resulting from holding the phone, and visual distraction that results from creating or reading messages. In a recent simulator study in the United Kingdom, seventeen participants (aged between 17-24 years) took part in the study. Reaction times of young drivers who used their mobile phones to send and read text messages showed a decreased ability to stay in the correct lane, a reduced ability to maintain a safe distance from the vehicle ahead as well as an increase in reaction time. In particular, reaction times were around 35% slower when writing a text message [Reed and Robbins, 2008].

Therefore, that text messaging while driving can significantly impair a driver's ability to maintain speed, and driver's lateral position on the road and it has the potential to be a particularly dangerous behavior to engage in while driving.

2.2.2 Nomadic Information and Communication Systems

The eSafety human-machine interaction working group defined nomadic devices as follows [eSafety Forum , 2004]: "A nomadic device is a device for information including entertainment, and/or communication that can be used outside and inside the vehicle by a driver while driving. It is not supplied or installed by the vehicle manufacturer."
According to this definition, nomadic information and communication systems cover a variety of electronic devices and they include the following categories [Janitzek et al., 2010]:

- Mobile phones.
- Personal Digital Assistants (PDA) offer a wide range of applications such as office software, calendars, navigation, and intent functions. They are usually touch screen and have large display. Smartphone are the common example of PDA these days.
- Smartphone has similar capabilities of PDAs combined with a mobile phone function. These devices are most commonly used via touch screen. Display size can be large (e.g. iPhone) or small (e.g. Blackberry).
- Personal Navigation Devices (PND) are portable electronic devices that have a positioning capability such as GPS as well as navigation functionalities. Some PNDs also offer certain PDA and display sizes are rather large and the devices are usually worked via touch screen.

With the technology improvement and decreasing prices, information and communication nomadic devices have become more and more popular in vehicle offering a diversity of functions (internet, email, fax, video messaging, and mobile phone services) which allow drivers to use their vehicles as a “mobile office” [Eost and Flyte, 1998]. Nevertheless, many of nomadic systems are not driver assistance and do not help driver with driving task since they are not specifically designed to be used inside the vehicle [Humanist, 2009].

2.2.3 Nomadic Auditory Entertainment Systems

Nomadic auditory entertainment system are increasingly used by drivers in the vehicle. These devices provide a wide range of personalized music with options to skip and search through the libraries of songs, audio books, video, and pictures. Drivers may listen to their portable music player through head-phones, or their vehicle speaker. And these portable music players can be placed anywhere in the vehicle, inside or outside the driver’s normal view. The important thing is that most of these devices are not designed to be used inside the driving situation and they do not conform to automotive HMI design rules and standards. However, some portable digital music players such as iPod have been integrated into some vehicles with customized electronic interfaces [Apple, 2014].

Salvucci et al. [2007] studied the effect of interaction with an iPod while driving in highway simulation environment. In the study, participants drove in a driving simulator while searching, listening to, and watching music, podcast, and videos while driving in a simulator. The result showed that when a participant performed selection tasks (searching for, listening to, or watching music, podcasts, or videos) notable reductions in vehicle speed were observed. However, listening to music or podcasts was not related to significant changes in vehicle speed.

The effect of portable music players are different compared to fixed, auditory entertainment systems and mobile phones since more effort and attention are required to scroll and select through numerous and complex hierarchical menu structure which can easily distract drivers from primary driving task. However, more research is needed to understand the driver distraction potential from these devices and investigate the car crash risk associated with them while driving [Salvucci et al., 2007].

2.2.4 Navigation Systems

Automotive navigation systems or route guidance is a satellite navigation systems designed to use inside the vehicles. Drivers can enter a destination into the system and the system automatically locates the user on the road and gives the fastest and shortest directions to that destination and guide drivers along roads. Navigation system have been available in three types: nomadic, original factory equipment, and aftermarket.

Recently many studies have been focused on the form and function that navigation systems should have and their effect on driving performance and safety. Although navigation systems may help people to reach their destination more quickly, with less time and uncertainty, the use of these systems could lead to distraction and jeopardize safety [Feenstra et al., 2008; Regan et al., 2001-5]. Navigation systems can distract drivers physically, visually, and cognitively by entering destination manually, looking at the visual display when entering destinations, and focusing on turning instructions or destination entry rather than driving task. Therefore, driver distraction can happen when drivers interact with navigation systems by two primary actions: destination entry and route guidance.

Destination entry is the first step for getting benefit from the navigation system and it is among those functions of concern that might be engaged while driving. It has been found by many in researchers that entry destination is simply too distracting to be done safely. Nevertheless, Green [1997] has shown that destination entry can be done in different real world scenarios, which make drivers tempted to perform it while driving. For instance, the driver entered the wrong destination and does not wish to stop the vehicle; or the driver does not know the exact destination at the beginning of the trip, enters a destination known to be close by, then enters the actual destination at a later time.

In an on-road study, Chiang et al. [2001] noted that drivers spent over 50% of their driving time looking at the device. Tijerina et al. [1998] and Tsimhoni et al. [2004] found that voice recognition systems have been shown to result in faster destination entry and less driver distraction. However, some of the navigation systems includes “lock out” feature while the vehicle is moving regardless of input modality to reduce driver distraction [Tijerina et al., 2000].

After a driver entered the destination information, the navigation system will give the instructions to the driver on how to reach the destination. Information regarding instructions can be presented by visual display, voice messages or both [Srinivasan and Jovanis, 1997]. Those systems that require visual attention to process navigation information result in more interferences the driving task because drivers need to look longer at the display. On the other hand, Dingus et al. [1995] found that the turn-by-turn guidance information improves the performance regarding usability, safety and visual demand. Moreover, route guidance systems which provide turn-by-turn instructions, rather than presenting complex holistic route information, are less distracting to the driver and present the most useable means of navigation.

2.2.5 Fixed In-vehicle Entertainment Systems

Fixed in-vehicle entertainment system include the auditory and audio-visual systems.

Auditory entertainment systems include the radio, and CD player. The in-vehicle radio is a standard feature in most vehicles. However, there has been little research about how interacting with radio can affect driver’s distraction. Although previous studies show that more than 70 % of drivers use audio entertainment while driving, audio output from radio or CD players is rarely investigated [Stutts et al., 2003; Jancke et al., 1994]. Stutts et al. [2003] found in “The Role of Driver Distraction in Traffic Crashes“ project that there was no increase in the total time spent by driving with eyes off the road or both hands off the steering wheel when a driver interact with auditory systems such as radio or CD player. On the other hand, manipulation of the audio systems such as tuning or adjusting volume resulted in a significant increase in the total time spent driving with both hands off the wheel and driving while looking inside the vehicle rather than focusing on the road.

There have been some studies that particularly investigated the effect of interaction with in-vehicle CD players on driving performance. In a study by Jenness et al. [2002], interaction with a CD player which includes selecting and inserting a CD, selecting a track, removing the CD, demanded high level of visual attention and had a significant decrease in driving performance - more frequent glances away from the road - than dialing a handheld mobile phone.

Based on AAA study in United States, adjusting the radio and CD player was found to be the second highest sources of distraction which is related to car crashes [Stutts et al., 2001].

Audio-visual entertainment systems such as TV and DVD players can be mounted to the front or of the rear seat. Aftermarket systems are also available, which attach to the vehicle centre console and it creates visual distraction if a driver is able to see the screen while driving. Some legislation such as United State prohibit any audio-visual systems that is not driver assistance from having mounted within driver's field of view because even the driver does not see the screen, cognitive distraction can occur from use of these entertainment systems. Kircher et al. [2004] investigated on how watching DVD player (mounted on the centre of console) while driving can affect driving performance. In general, DVD player had a negative effect on drivers' ability to react to a critical incident and driving performance decrements were most severe when the visual modality was engaged.

In another study [Funkhouser and Chrysler, 2007], the effects of in-vehicle DVD players on driving performance was examined. Nine drivers drove 5 laps in equipped vehicle around a 10.1 mile closed course containing several curves: two laps were designated as controls, one lap while watching a DVD program, one lap while listening to a DVD program, and one lap while manipulating the DVD player. Drivers that watching and manipulating the DVD player were less likely to notice outside events and applied brakes for a greater proportion of total driving time compared with listening or control laps. During the laps involving the DVD player, they also reacted slower to the events presented in their periphery. It was also found that while driving, drivers looked at the DVD for 15% of total driving time. Finally, participants drove significantly slower when watching the DVD player and slightly slower when operating it.

2.3 Driver Safety Guideline and Standard

Generally speaking, guidelines describe how something *should* be done, while standards describe how something *must* be done. Guidelines and standards usually apply to either product design or performance.

Design guidelines and standards indicate physical characteristics such as tolerances and operating temperature. Design guidelines and standards are useful and practical, when a subject has been well investigated and all information concerning the subject is gathered and stabilized. For instance, minimum size of a character and bumper heights are requirements that are needed to be considered from design guideline and standards to guarantee legibility in vehicle physical interfaces.

On the other hand, performance guidelines and standards work with measurement and functionality such as time and errors when entering the destination into an in-vehicle navigation systems. Performance guidelines and standards are considered where the technology is growing rapidly.

Following the design guidelines for ease of use can reduce opportunities for distraction, although performance standards more directly discuss about the distraction problem. However, both types of documents are equally important.

Therefore, in order to minimize driver distraction within the vehicle, design and/or performance guidelines and standards are needed to be applied by engineers and designers for designing and evaluating a driver interface for motor vehicle communication and information systems such as navigation, traffic information, text messaging, and entertainment. It should also be mentioned that how much these systems distracts drivers while driving depends on the task and its demand required to perform the task, and not on devices. Thus, all products used within the vehicle from original equipment manufacturers (OEM) and aftermarket products to portable devices are the same from distraction point of view.

Although applying guidelines and standards is expensive and time consuming, it is worth to use them since noncomplying interfaces can easily put drivers and other people's life in great danger or make them undesired by customer. Most customers do not want to read long documents and take a class to operate with their vehicle, they expect their vehicles to be easy to use and most importantly safe.

Regarding this, there are quite a large number of guidelines and standards to assist in designing driver interfaces to enhance safety and ease of use, and reduce distraction. These guideline and standards may concern not what is produced, they mostly focus on the process of how it is produced to cover when and how design reviews and tests are done and how the entire process must be documented. In the following section three different approaches to guideline and principles will be reviewed.

2.3.1 Overview Of Existing Guideline and Standard for Driver Interface

There are two groups of guidelines and standards including, *specific* automotive safety and usability standards and *generic* standards regarding safety and usability. Moreover, these standards can be process-based, performance-based, or design-based. While process standards mostly focus on user-centered design, the performance and design standards are more specific. Standards are the procedure or specifications that show how things must be done and developed, while guidelines concern how interfaces should be designed and developed by different organization, usually written under contract to U.S. Department of Transportation [Schindhelm et al., 2004; Green et al., 1995].

There are numerous specific automotive guidelines. The U.S. Department of Transportation (U.S. DOT) funded the first set of guidelines, the University of Michigan Transportation Research Institute (UMTRI) guidelines, continued by the Battelle guidelines [Schindhelm et al., 2004]. The UMTRI guideline covers general guidelines and specific design principles of manual controls, speech, visual displays, auditory displays, navigation interfaces, traffic information, phones, vehicle monitoring, and warning systems. In addition, the supporting literature is described for every guidelines [Schindhelm et al., 2004; Green et al., 1995]. However, Battelle guidelines focus on heavy vehicles concerning navigation, warning systems, in-vehicle signs, trucks, and other subjects. The guidelines include physical ergonomics such as control sizes. Each Battelle guideline is completed by the rationale, application notes, references, and a four-star rating of the supporting evidence. For instance, according to Battelle guideline, road segments should be color coded (green, yellow, red) to indicate the mean speed of the traffic flow [Campbell et al., 1998]. In 2000, the National Highway Traffic Safety Administration (NHTSA), an agency of U.S. DOT, sponsored several events focusing on driver distraction. The guidelines include recommendations to limit the time a driver must take his eyes off the road to perform any task to two seconds at a time and twelve seconds in total. These guidelines applies to advanced information and communication systems such as navigation systems and the visual manual interaction within the vehicle while driving.

The European Union (EU) human-machine interface guidelines were developed and later improved to design and assess in-vehicle displays, information and communication systems regarding safety and usability within Europe. The original EU guidelines were very brief, but they were expanded and renamed as the European Statement of Principles (ESoP) [Commission of the European Communities, 2005]. The 1999 EU guidelines mostly focus on the overall system design, installation, information presentation, interaction with controls and displays, system behavior, and information (documentation) about the system. The EU guidelines does not cover aspects of information and communication systems not related to HMI such as electrical characteristics, material properties, system performance and legal aspects. These original EU guidelines also were the basis for Alliance of Automobile Manufacturers (AAM) guidelines and had the impact on the development of a checklist and guidelines by the Transport Research Laboratory (TRL) [Schindhelm et al., 2004; Commission of the European communities, 1999].

The AAM statement of principles had an important impact on driver interface design. Although their scope declares that the AAM principles apply only to advanced information and communication systems, these principles should also apply to traditional information or communications systems such as entertainment systems since the essential goals - reading displays or pressing buttons - and method of implementation are the same. The AAM document includes performance criteria, verification procedures and examples for each guideline which are divided into the following five categories: installation, information presentation, interaction with displays and controls, system behavior and information about the system [Schindhelm et al., 2004; Alliance of Automobile Manufacturers, 2006].

At the same time, the Japan Automobile Manufacturers association (JAMA) has developed guidelines to reduce distraction which are followed by all Japanese OEMs and aftermarket dealers. Although JAMA guidelines are brief, they cover very specific requirements relating to display location and limitations on what can be shown in a moving vehicle. For instance, it is not allowed to place a display in 30º or more below the driver's viewing plane [Schindhelm et al., 2004; Nakamura, 2004].

However, the Society of Automotive Engineers (SAE), the leading international professional organization of automotive engineers, developed two SAE recommended practices in a somewhat different direction. SAE recommended practice J2364 [Foley, 2000] includes two methods and criteria to test whether visual manual task should be performed while driving or not. Although SAE practice J2364 applied to navigation and route guidance entry tasks, this practice can be applied to other visual manual tasks. The static test procedure needs 10 participants to complete five practice trials and three test trials of the task in question such as entering a destination in parked vehicle, simulator, or laboratory mockup. The task is acceptable if the task takes 15 seconds to be completed. The idea behind this practice is that the longer an in-vehicle task takes to be finished by drivers, the more distracted are the drivers from keeping their eyes on the road, and the greater is the possibility of a car crash.

ISO standards documents have been developing by ISO Working Group, groups of experts from all over the world. ISO Working Group negotiate all aspects of the standard, including its scope, key definitions and content. There are various kind of ISO standards [International Organization for Standardization, 2002; International Organization for Standardization, 2007] which most of them are general and do not contain all the detail information which can be found in other guidelines such as UMTRI. Since it is not easy to reach agreement within the working group, measurement methods are usually introduced without the acceptance criteria regarding safety. Nevertheless, national standards organizations, technical societies such as SAE, and government organizations such as U.S. DOT often consider ISO standards instead of their own standards. Therefore, ISO standards are very important. ISO standards consider design, design process, and performance assessment. Although design standards are quite general and have few assessment criteria, they can be useful regarding distraction. Regarding performance assessment, 16673 standard explain a test to assess the visual demand of a display by periodically blocking (occluding) the driver’s view of the display. The display is visible for 1.5 seconds and occluded for 1.5 seconds [Schindhelm et al., 2004].

3 METHODS FOR MEASURING DISTRACTION

Currently drivers have a strong desire to use new functionalities and services with higher level of quality and design in their vehicle. They expect latest technology and want to have access to a range of entertainment, information, communication, and advanced driver assistance systems such as navigation systems. These technologies can easily distract drivers depending in large part on the way they are designed and used. Therefore, evaluation methods and metrics are needed to assess the effects of different in-vehicle technologies on driving performance to ensure of the safe design, deployment, and use of these devices. A large number of methods and metrics are already available for evaluating the impact of driver interaction with secondary tasks on driving performance. Some of these methods use high technology equipment such as driving simulators to measure a range of driving performance metrics, while other methods such as the visual occlusion technique use low technology equipment to just measure particular aspects of distraction. This chapter first will discuss different methods that have been used to measure driver distraction. At the end of the chapter both advantages and disadvantages of each method will be elaborated as a measurement tool.

3.1 On-Road Test Track Studies

On-road study is one of the most realistic ways of measuring the distracting effects of in-vehicle tasks. In this method, drivers drive an instrumented vehicle on a real road for a specified period of time while driving performance data is collected. After that, collected data will be compared to a baseline condition such as driving when not interacting with the devices. Although the collected data is relatively accurate in the on-road study, this method is very expensive and time consuming since there are a large amount of data from real driving situation and it takes few months or sometimes years to complete a study. Therefore, on-road study is rarely used as a method to measure driver distraction. Test track studies also work with real world driving to measure distraction and have been extensively used to examine the distracting effects of secondary tasks. In these studies the drivers drive a vehicle equipped with one or more in-vehicle devices on the real road or closed test roads. Driving performance data while engaging with secondary tasks, such as entering destination information, is collected by a data logger, an observer, or instrumentation embedded in the roadway. Then, the collected data is compared with a baseline condition to evaluate the level of distraction of related secondary task. In this method, the collected data is not as close to the real world data as in the on-board method since driving is under control condition to reduce the safety risks. Nevertheless, a closed road can affect the data collected especially when the route is short and there is no traffic because drivers feel more confident to spend more time on looking inside the vehicle rather than on road in the real driving condition [Green et al., 1993; Harbluk et al., 2002].

3.2 Driving Simulator

The most common approach to measure distraction is to use driving simulators since they offer a good balance of cost, time, validity and control over an experiment. Thus, using driving simulators can help researchers to have an amount of driving performance data in a controlled, comparatively realistic and safe driving environment.

There are various driving simulators with different characteristics which can affect their realism and the validity of the results obtained. Generally, they are categorized into low-level, mid-level, and high-level driving simulators.

High-level driving simulators have a realistic driving environment and motion base which are equipped with realistic components and layout such as a colored, textured, visual scene with roadside objects such as trees. However, high-level driving simulators can be much more expensive to construct and operate than other equipment.

Mid-level driving simulators have a realistic driving environment and a simple motion base with large projection screens.

Low-level driving simulators have a less realistic driving environment with only main markings such as road line markings which are reproduced in the visual scene. Moreover, they are a low-cost, fixed-base simulator.

There are a number of justifications show using driving simulators is more useful than on-road and test track studies.

Some research is too dangerous to be conducted on the road but simulators can provide a safe environment to conduct such research. For instance, evaluating the distracting effects of in-vehicle systems on driving when there is more than one vehicle, is potentially dangerous to be done by test tracks methods. In contrast, driving simulators provide a safe condition for the examination of these issues using multiple vehicle scenarios, where the driver can negotiate while engaging in secondary tasks such as interacting with other vehicles or road users while using certain devices [Reed and Green, 1999].

Modifying a simulator to evaluate new in-vehicle systems may be less expensive than modifying an actual vehicle with those features and ensuring that the changes are roadworthy or meet the design rules [Reed and Green, 1999].

Greater experimental control can be consistently applied in driving simulators compared to on the road studies. In driving simulator studies, difficulty of driving tasks can be accurately specified and some variables such as weather can be ignored [Reed and Green, 1999].

A wide range of test conditions such as night and day, different weather conditions or road environments can also be managed much easier in driving simulator. However, these conditions can make the driving situation difficult or dangerous in an on road examination [Reed and Green, 1999; Srinivasan and Jovanis, 1997].

Nonetheless, the use of driving simulators as a research tool can have a number of disadvantages.

Driving simulators, especially high-level simulators, can also be very expensive to set up and operate. They are often much more expensive than other equipment used to measure driver distraction such as visual occlusion goggles [Reed and Green, 1999].

Data collected from a driving simulator may not be realistic since the study includes the impact of learning how to use the simulator or any in-vehicle systems.

Simulator discomfort can be another problem in driving simulator studies, especially for older drivers, which has a negative effect on the collected data.

The most problematic issue of driving simulator research that has an important impact on driver distraction research is the effect of the simulator on the driver's priorities in relation to the driving task and secondary tasks (e.g. interacting with in-vehicle entertainment systems). Drivers feel more confident and safer in the driving simulator than a real on road test since the result from driving errors in the simulator is not in serious and this can affect their behavior and the amount of cognitive resources they devote to performing concurrent tasks. Therefore, a driver may look away from the road, or remove their hands off the steering wheel for longer time when performing secondary tasks such as dialing a phone or texting a message in a simulator than they would in the real world. As a result, data that is collected in a driving simulator may not pass the validity criteria for being used in human factors research.

3.3 The 15-Second Rule

In 1990, SAE International tried to develop a recommended practice for determining whether or not a specific navigation system function should be accessible to the driver while driving. The draft recommended practice (SAE J2364) established a design limit for the total time required to enter information into navigation systems while driving. [Foley, 2000]

The document stated that if an in-vehicle task could be completed within 15 seconds by a sample of drivers in a static setting such as a parked vehicle, then the function was suitable to perform while driving. While this standard was developed to assess route navigation systems, it can also be applied when evaluating the distracting effect of any in-vehicle system and has an advantage over many other measurement methods of being simple to use.

NHTSA [2012] conducted a preliminary evaluation of this proposed rule to determine how well the results from a stand still vehicle correspond to the results collected from the driving situation. Ten participants, five females and five males, aged 55 to 69 years, drove around a 7.5-mile test track and completed 15 tasks, including navigation system destination entry, radio tuning, manual phone dialing, and adjusting the Heating, Ventilation, and Air Conditioning (HVAC) controls in a test vehicle. Correlations between static task performance and dynamic task performance were relatively low. The results revealed that such tasks took less time to complete while the vehicle was moving than when it was the stand still. In addition, it often took longer than 15 seconds to complete the comparison tasks while the vehicle was moving. Therefore, static measurement of task completion time could not reliably predict the acceptability of a device.

However, the 15-second total task time rule is supported by some researchers as it achieves its fundamental purpose of reducing the performance of tasks with long completion times in driving situation and may provide a guide for designers as to which in-vehicle systems should and should not be available to drivers while driving [NHTSA, 2012].

3.4 Eye Glance Studies

Visual behavior while driving plays an important role in driver distraction studies. Visual distraction caused by the use of in-vehicle systems such as radios, and phones has drawn a lot of attention in many recent researches. There are two main approaches to measure visual demand or distraction: 1) the use of an eye tracker and 2) manually extracting eye glance locations and durations from video recorded data [NHTSA, 2012].

The eye glance method measures visual behavior by recording the duration of eye glances at particular objects in the driver's field of view. When drivers perform a secondary task while driving such as entering a destination information, they usually complete this task through a series of short glances which is often between 1 to 2 seconds. Eye glance researches record and measure the duration and frequency of glances when drivers perform a secondary task which gives a measure of the total "eyes off road time". Therefore, visual demand associated with performing the task can be determined by the total eyes-off-road-time which is a valid and widely accepted measure [Haigney and Westerman, 2001].

Eye glance behavior has been usually measured by using a video recorder to record the driver's eye and hand gestures. After recording, the tapes are analyzed frame by frame to collect the eye glance data. Nevertheless, video recorder technique in order to obtain eye glance information is highly labor intensive, time consuming, and expensive [NHTSA, 2012]. Currently, sophisticated head and eye tracking devices make this process easier and allow for the real-time measurement of duration and frequency of eye glances, scan paths, and eye-closures.

3.5 Dual Task Studies

The limits of cognitive capacity make it difficult for humans to perform different tasks at the same time, depending on the levels and types of demand of each task. Therefore, the concurrent performance of two tasks will result in poorer performance of either or both tasks since greater attention is allocated to one task and the performance of the other task is adversely affected. In a case of driving, a dual-task happens when the driver concurrently tries to engage in a secondary task such as talking on the mobile phone while performing the primary task (e.g. driving). The driving performance may decrease as the conversation becomes interesting and the driver allocates more attention to it. On the contrary, the conversation may be disrupted if a road environment unexpectedly becomes dangerous. Thus, interacting with in-vehicle systems can reduce driving performance since drivers allocate greater attention to using the device and less to the driving task [Haigney and Westerman, 2001].

Dual-task studies assess the effects of performing one task on the performance of another concurrent task. In a case of driver distraction, these researches examine the effect of engaging in secondary tasks, such as dialing a mobile phone or entering destination information into a navigation system, on driving performance.

In one dual-task study, the authors [Martens and Winsum, 1999] shows a tool for measuring distraction which is the Peripheral Detection Task (PDT). The PDT was developed to measure driver mental workload and visual distraction. With this method, drivers needed to perform several tasks while responding to PDT targets such as lights in the environment. As drivers become more distracted by the primary task, they respond slower and finally fail to detect more PDT targets. Hence, performance of the PDT task gives a measure of how distracting the primary task is.

Furthermore, there has been some research to investigate the validity of the PDT method for measuring level of distraction caused by in-vehicle systems. The authors [1999] examined the validity of the PDT to measure workload and driver distraction by using a driving simulator. Participants were required to drive on an 80 km/h road and motorways while responding to a red square that was presented on the simulator screen in front of the driver's periphery during one second. In addition, participants interacted with either a driver support system that issued tactile and auditory warnings or without a driver support system and respond to a red square as soon as it was detected. At different times along the road, there were also critical incidences such a braking lead vehicle or a sharp curve. Higher reaction times and failure to detect the red light were interpreted as the result of increased workload or greater distraction. The results showed that as the complexity of the driving task increased, response times to the PDT were longer and failures to detect the signal also increased. Moreover, when there were speech-based warnings by the driver support system for drivers, PDT performance decreased. The result finally revealed that the PDT is a valid and very sensitive method for measuring peaks in driver workload and driver distraction resulting from a critical scenario or messages provided by driver support systems.

However, one of the problematic issues of most dual-task studies is that they do not examine performance trade-offs between the driving and the distraction tasks. Many studies focus on measuring the effect of performing two tasks that are distracted and if one of the tasks has a worse effect on driving performance than the other, then it is the most distracting task. Therefore, in order to have a better understanding of the distracting effects of in-vehicle systems, it is important for research on driver distraction to examine the performance trade-offs between the driving and the distracting tasks.

3.6 The Visual Occlusion Method

The Occlusion method is a technique to measure the visual distraction of a secondary task, such as entering data in navigation systems, while driving. This method can be a good replacement of eye tracking equipment which is usually time-consuming and very expensive [Foley, 2008].

Based on the visual occlusion method, drivers only need to look the road part of the time and the rest of the time can be allocated to secondary tasks. Therefore, the driver's vision is partially or fully occluded during the performance of the secondary task by the use of a shield or another similar device that opens and shuts at different time intervals. Figure 2 shows the pattern of back-and-forth eye glances to and from the roadway by the driver in the dual-task condition which is the basis of the occlusion technique. This technique simulates a driving situation where drivers look at the road and interact with a device. The occluded part simulates the time drivers are looking at the road and the viewing part is the time that they are looking at the in-vehicle systems.

Vision	Occlusion	Vision	Occlusion

Figure 2. Vision and occlusion intervals.

Using the Occlusion method makes it possible to evaluate whether an in-vehicle task such as changing the music or tuning the radio can be successfully performed using only short glances which is between 1 to 2 seconds and if drivers can easily resume the task after interruption.

The illustration of use of the occlusion technique and time measurement are shown in Figure 3. The occlusion technique measures the performance of a driver on a secondary task both when there is no occlusion during the performance of the task which is total task time unoccluded (TTTUnoccl) and when the task is periodically occluded total task time occluded (TTTOccl) [Foley, 2008].

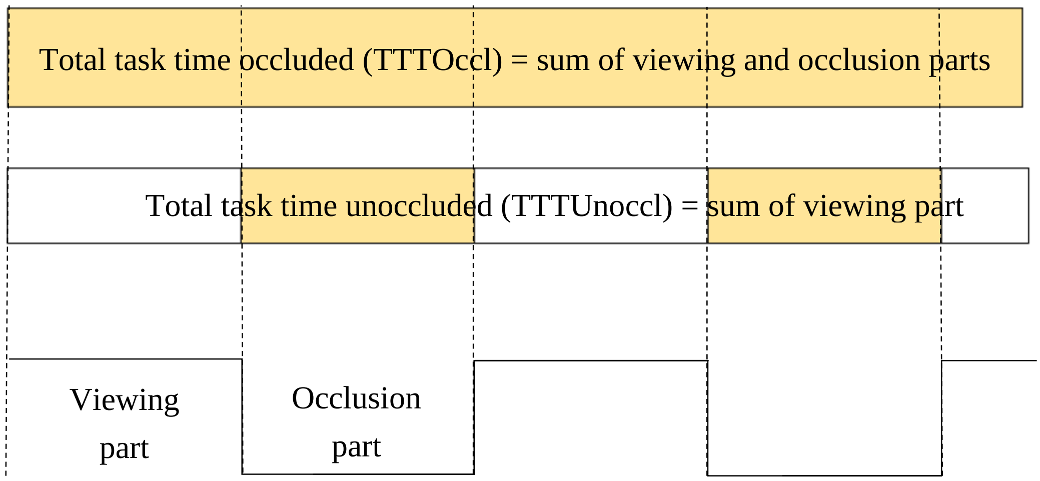


Figure 3. Occlusion and time measurement.

Motorcycle helmet with visor, LCD goggles and LCD face shield are the most promising methods for achieving occlusion since they provide the greatest control and are technically feasible.

Occlusion has been widely studied and evaluated to check whether it is a valid technique for measuring visual distraction. Baumann et al. [2004] evaluated the use of occlusion technique in an on-road information systems study. Thus, two experimental studies were conducted. In the first study, participants were required to enter destination information into a navigation system under one of three conditions: in a parking lot without occlusion, in a parking lot with occlusion and driving. In a second study, the occlusion method was compared to a global evaluation standard (15-second rule) based on the total task time. The results of both experiments revealed that the occlusion method is a useful and valid method for evaluating in-vehicle systems and is suitable for the simulation of real-world conditions.

3.7 Comparative Overview of Methods for Measuring Distraction

Numerous studies have investigated the effect of secondary tasks on driving behavior. However, the accuracy of the studies varies significantly, and depends on the methods used and the conditions under which the studies were performed.

Each of these approaches provides a slightly different view on the problem and only one approach cannot provide all the information needed to make policy decisions. It is the results and outcomes from various approaches that provide the basis for informed decision-making. Table 1 shows the summary of different methodologies, their benefits, and drawbacks [Stutts et al., 2001; Mccartt et al., 2006]. For example, in the experimental studies, although it is possible to monitor drivers' behavior closely and control the situation, the study is very expensive and the result is not very realistic.

	Methodology	Benefits	Drawbacks
Experimental	Takes place in controlled settings, for instance simulators, test tracks, or sometimes on roads.	What driver is doing can be closely monitored.	Not very realistic. Expensive and small number of drivers generally involved. Given small size which is difficult to generalize results.
Observational studies			
Fixed observational studies	Observer records information about drivers as they pass a selected location.	Provides direct Information about the types and occurrence of secondary tasks that drivers try to do while driving.	Information limited by how accurate observer is at recording behavior as vehicle goes by (limited time and potentially limited visibility), and by representativeness of observation sites. Studies only provide a snapshot assessment.
Naturalistic studies	Participants allow their driving behavior to be recorded during a period of normal driving (vehicles equipped with sensors and cameras). For instance, on-road studies.	Studies usually conducted on public roads, thus the result is more valid than those in experimental studies.	Drivers are aware that vehicles are monitored, which can affect driving behavior. Studies are costly and are less controlled – confounding factors may explain the results. Datasets resulting from studies are usually very large and can be challenging to analyze and interpret.
Crash-based studies	Real life crashes are examined to determine whether a distracting activity was involved in the crash.	Provide the most accurate information about the safety implications of performing secondary tasks while driving.	Difficult to determine whether driver distraction was a contributing factor in a crash since police reports do not usually include occurrence of a distracting activity and drivers may not have interest in reporting the truth about their own distraction. Very likely that the occurrence of distraction is under-reported in crash studies.

Table 2. Different type of studies and their benefits and drawbacks [Stutts et al., 2006].

As mentioned before, the most suitable method greatly depends on what aspect of driver distraction is being examined. The PDT method or visual occlusion technique are probably the most appropriate methods to measure the visual distraction that happens by the use of in-vehicle systems. While PDT is more appropriate for measuring the visual demand required by a specific device, visual occlusion method is more appropriate for assessing if a task such as a destination entry task can be completed in series of short glances or it needs a constant visual attention for a period of time. On the other hand, driving simulator works as a promising tool in studies that focus on safety, validity, and measuring driving performance and in-vehicle tasks at the same time. Moreover, on-road studies are more dangerous to conduct and are less experimentally controlled than simulator studies.

4 RESEARCH METHOD

In this chapter we intend to describe our approach to this study. This will be done by explaining the method used and the role of the researcher as well as the objective metrics obtained from data.

The work was performed in HiQ Company and it was part of a research project (SICS - Safe Interaction, Connectivity and State) which will continue to be developed and accessible to OEMs and third-party developers as a fully functional product. In addition, the framework was tested by two case study applications to evaluate them based on the safety metrics.

4.1 Design Science

Design Science Research is a form of research methodology which focuses on the design and development of an artifact. Design is a crucial part in the information systems and organization which consists of the purposeful structure to achieve a goal. Design science research requires the creation of purposeful artifact that must either solve a problem that has not yet been solved, or provide a more effective solution. Furthermore, the artifact must be evaluated thoroughly, and the results of the research are needed to be presented effectively [Hevner et al., 2004].

As described by Hevner et al. [2004] the fundamental principle of a design research is understanding of a design problem and finding solutions for it, by building and application of an artifact for the problem. The followings describe seven guidelines derived from this fundamental principle and they can be interpreted as a mean to understand the requirements for an effective design research. This research has tried to apply the following guidelines along the way.

1. Design as an artifact: The research must produce a valuable artifact in form of a model, a method, a construct or an instantiation. The artifact designed in this thesis work is an Android framework for evaluating in-vehicle applications regarding safety.
2. Problem Relevance: The main objective of design research is to develop a software based solution to the problems that are relevant to specific business problems.
3. Design evaluation: The quality and effectiveness of an artifact must be evaluated by an exquisite evaluation methods. There are different methods to

evaluate a design science research. We have performed two case study applications to evaluate the research as an observational method and further on performed and analytical approach by defining and measuring certain metrics.

4. Research contribution: Design science research must provide clear contribution in up to three different areas. The design artifact itself, the creative development and extending of an existing foundation and creative development of the evaluation methods that can be observational, experimental or analytical along with new metrics for an evaluation.
5. Research Rigor: In a designed based research rigor is derived from the effective use of knowledge base. It depends on the researchers to select appropriate techniques to construct an artifact and further evaluate the artifact using appropriate methods.
6. Design as a search process: Design science is an iterative process. This kind of research can be viewed as utilizing available tools and methods to obtain a desired end and refine solutions. The case studies and produced artifacts are all developed in an agile and iterative manner that refined in several iterations.
7. Communication of research: The result of the design research must be properly communicate for the technical-oriented and management-oriented audiences. The end result of this research has been presented for various audiences including software developers in HiQ and product owners and line managers both in HiQ and Volvo.

4.2 The Role of the Researcher

The researcher of this thesis has Three years' experience of Java and Android programming. She worked as a researcher and developer in this thesis and developed the whole Android framework except the simulator part. She has also contributed in developing one of the case study applications (Predicted Range Interval Next Generation) that is used in this thesis.

4.3 Test Procedure

Tests for this study conducted in HiQ Company using Automotive Grade Android (AGA) simulator. Two developers who developed two in-vehicle applications participated in the experiment. Before the experiments, the instruction was given to the participants in order to use the framework inside their applications. Then they were asked to deploy the framework and regarding this, two tasks were chosen form each application to be evaluated regarding safety. The driving simulator was described and participants practiced driving simulator until they felt comfortable. Since participants developed the applications no practice was needed to get familiar with the tasks. After that, the participants were asked to start driving and they were not allowed to stop between the tasks. During the test, all the information that were needed for measuring safety metrics collected from application and simulator.

4.4 Application's metrics

For the goal of interface evaluation a number of metrics were analyzed. Most of these metrics were chosen based on the literature review. Since there are various issues with data collection and data quality limitation, all the metrics will not be used in the thesis work.

4.4.1 Total task time

This metric presents the time between start and end of a task. Total task time (TTT) is an important attribute of a task because of high impact on other duration-related metrics especially in human machine interaction design [Burns et al., 2010].

TTT has a strong correlation to the metrics such as total glance time and dynamic task time. In NHTSA guideline, task duration is often explained as the most critical issue and in some cases; task duration could be identified as the only variable of importance.

Remarkably it is also possible that an interface can be slow, but providing significantly better comfort and vehicle control. Study from Sasanouchi et al. [2005] and also results from Horrey et al. [2003] suggest that even if TTT in the interaction with head up display is longer, standard lane deviation is still smaller, therefore TTT cannot be directly related to safety. Moreover, personal approach to complete a task could affect TTT and makes it hard to evaluate the safety of the task based on TTT since some people make breaks while performing the task. Therefore, TTT from safety perspective must be interpreted in combination with other safety relevant metrics.

Overall, a task with longer duration has a negative effect on drivers' safety because it will take more time for drivers to interact with the interface and they can be distracted from the primary driving task. Consequently, for some tasks that requires longer time to be completed than others like navigation entry task, guidelines are needed to limit the task duration. For instance, NHTSA [2012] limited total task time for a task to a maximum 12 seconds.

4.4.2 Number of interactions per task

This metric includes number of interactions with a touch screen per a specific task. Currently, modern cell phones and in-vehicle systems support functions such as texting and web browsing that involve greater physical manipulation. Text entry is one of the most dangerous form of driver distraction since interaction with a touch screen can increase the total task time and create greater visual demands on the user. In a recent simulator study, Crandall and Chaparro [2012] found that text entry with touch screens increases the need to monitor the input and visually confirms that the input is correct. It was also found that participants made a lot of text input errors using a touch screen interface which may show that they focused more on driving task over text entry. However, poor lane change behaviour and high mental and physical worked load showed the poor driving performance, which increase a risk to driver safety.

Therefore, touch interaction has a direct effect on the road safety. The more we have touch interactions during a specific task, the more visual demand is needed for a driver and he/she spends more time looking away from a road and this leads to crash or near-crash accident.

4.4.3 Errors on task

This metric shows the number of errors made while performing a specific task. According to NHTSA, an error has occurred if a driver has to backtrack (return to the previous state which has previously been traversed) performance of the task or delete entered input. Therefore, a task with high number of error (more than 50 percent) is determined as an “unreasonably difficult task” for performance by a driver while driving and unreasonably difficult tasks are not recommended for performance while driving. Thus, these tasks should be locked out because it can easily distract driver and put drivers’ safety in danger [NHTSA, 2010].

In the occlusion research done by Foley [2008], task errors is used as a parameter to measure safety and driver distraction. The result showed that if a participant cannot complete a task under occlusion or makes excessive errors, then that is a strong indication that the task should be redesigned if it is desired that the driver have work with the task while driving.

Tchankue et al. [2011] studied the effect of an adaptive in-car communication system (ICCS) on driver distraction and safety. Although task errors was considered as a usability metric in this study, it had a great impact on the driver distraction and safety analysis. The results showed that the adaptive interface have both usability and safety advantages, including decreasing cognitive workload which resulted from high usability.

Moreover, errors on task must be observed by an experimenter during the study and it cannot be got from the interface of in-vehicle systems or smart phones automatically. Therefore, this metric will not be used during this thesis work.

4.4.4 Task completion rate

Task completion rate or success rate indicates the number of completion of a task within a specific time. It also shows that how many times a driver starts a specific task but could not reach the end state within a specific time [NHTSA, 2010]. In NHTSA guideline, if a task is completed within 12 seconds, it is counted as a completed task.

Although task completion rate do not have direct effect on the safety but they will function as a weighting system in our risk analysis.

4.5 Vehicle’s metrics

In addition to those metrics analyzed from the applications, more metrics could be derived from the logged data in the vehicle. Because of the time limitation within the context of the master thesis, the most available metrics will be used.

4.5.1 Standard deviation of lane position (SDLP)

Lane keeping shows the position of a vehicle on the road in relation to the center of the lane which the vehicle is driven. One of the most commonly used lane keeping metrics is standard deviation of lane position. Research suggest that drivers make a great number of lane position deviations while talking or dialing on either hands-free or hand held mobile phone, even when they are driving straight on the road with less traffic [Green et al., 1993; Reed and Green, 1999].

Standard deviation of lane position correlated only with mean number of glances made to any location during performing a task, the mean number of glances made to the road, and the mean number of glances made not look at the road. These are difficult to interpret without other significant relationships. As the number of glances to the road increased, the standard deviation of lane position increased. A reasonable interpretation for correlations between SDLP and glances to the road is that longer task duration is associated with more careless lane keeping, either because of the workload effects or the continuous effort required to control vehicle over longer periods. The longer the task duration, the more glances are needed and the higher the SDLPs are resulted. In contrary, the more times the driver look at the road, the better lane keeping and smaller SDLP s/he could have [Angell et al., 2006].

Thus, SDLP could be considered as safety metric since bigger SDLP increases the risk of lane departure and visual workload which might lead to a great driver distraction and increase the car crash risk. Because of the simulator's restriction, this metric is not used in this thesis work.

4.5.2 Steering wheel reversal rate (SRR)

This metric is used extensively in many forms of driving research. In driving distraction research, steering wheel movements are considered to indicate the secondary task load.

In normal driving situation, when a driver is not engaged in secondary tasks, they will make a small number of corrective steering wheel movements to keep their vehicle on the lane. However, involved in a secondary task, especially visual manual task, a driver will make large number of steering wheel adjustments to maintain their vehicles' position.

Increased SRR values shows that greater effort is needed for drivers to cope with corresponding visual or cognitive workload. However, as with most known metrics there is no known exact relation between SRR and driving safety [Marrkulla and Engstroem, 2006; Johansson et al., 2004]. In addition, steering wheel related metrics are influenced by most of the surrounding factors such as traffic, speed, lane width, road curvature, driving strategy, and so on [Östlund et al., 2005]. Because of the simulator's restriction, this metric is not used in this thesis work.

4.5.3 Average vehicle speed

Speed has a great impact on driver distraction and it is mostly used as a dependent variable in driver distraction field. Because of the simple measurement, speed metrics are the most commonly used metrics in driving behaviour studies. Average vehicle speed is one of the speed-related metrics which is an indicator of average driving speed during the task.

However, the effects of mental workload and distraction on speed are not as easily interpreted. In several studies, it has been found that visual distraction leads to decreased speed, which has been attributed to the idea that the driver reduces speed in order to cope with the reduced visual demand. Nevertheless, cognitive load has been found to influence speed less and inconsistently. Östlund et al. [2005] studied the effects of visual and cognitive load on driving performance. The result showed that speed was unaffected by the cognitive task, although there were some indications that the speed increased for the highest cognitive load levels. The same was found in a study on mobile phones [Patten et al, 2004], where speed tended to increase while the drivers were engaged in a mobile phone conversation with a hands free unit. This effect may result in a loss of speed controlling, which could endanger drivers' safety.

In another Lab and simulator studies [Green et al., 1993; Reed and Green, 1999], it was found out that there is greater variation in driving speed when drivers use their mobile phones, both hands free and handheld phone. It has been demonstrated that drivers tend to reduce their speed when talking to their phone to reduce primary task demand or increase safety.

Srinivasan and Jovanis [1997] also found that average vehicle speeds were lower when drivers manually enter information related to the navigation system in a driving simulator.

5 IMPLEMENTATION

In order to measure distraction of in-vehicle applications as drivers interact with those applications, it is decided to implement an Android framework which makes it possible to collect real-time data for safety analysis

In this chapter, first the whole system is reviewed and the implementation of the framework including safety evaluation library, server side, and database design are discussed followed by the presentation tool. In Addition, the use of automotive Android simulator within the thesis in order to get the vehicle data will be presented. Finally, this framework is applied and tested by two case study projects which are in-vehicle applications and the findings are elaborated.

5.1 System Overview

The system's purpose is to help OEMs and third-party developers to get safety feedback from their in-vehicle applications in the real driving environment. The system architecture is based on the client-server model which is illustrated by Figure 4. The client side of the system is developed as an Android library for collecting feedback data, while the server side program is responsible for analyzing the collected data. The client side library basically provides APIs for client's apps to collect critical data in various parts of their application.

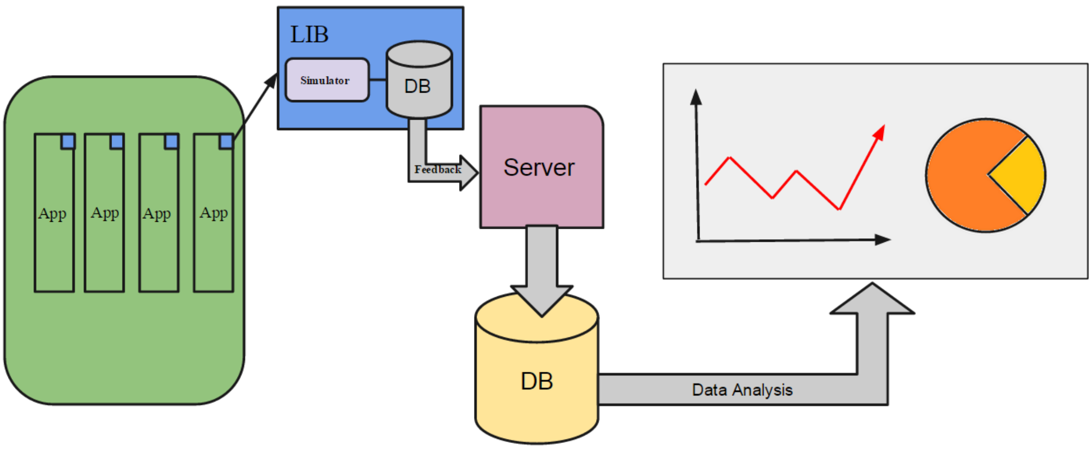


Figure 4. Architecture of the framework.

Android was chosen since it is a growing mobile platform that is supported by a wide range of mobile phone brands as well as in-vehicle systems. The system stores everything on the server side database and calculate the required metrics. Then, the information is shown in different charts as a feedback for the safety analysis.

The main limitation in this thesis prototype is that the Android devices which contain the in-vehicle applications such as smartphones or head units shall communicate with the server constantly. Furthermore, they have to have access to the same Wi-Fi network that is secure, reliable, and steady. In the prototype version the client side is getting vehicle's key data such as speed of the vehicle using a simulation software. In production version of the system will be connected to the vehicle's canalyzer which will provide all the data collected by various sensors built in to the vehicle itself.

5.2 Safety Evaluation Library

Safety evaluation library is an Android library that is used during the development of in-vehicle applications by OEMs or third-party developers. This library contains all the Java classes, Android components and resources that are required to get the data from the in-vehicle applications and vehicles while drivers interact with the applications. Different components and services within this library is illustrated in Figure 5.

Considering the safety evaluation library, all the in-vehicle application's information such as start and finish time of a task as well as the vehicle metrics such as speed are collected at the same time. Program 1 and 2 show two one liners that need to be used by third-party developers when a task starts and ends. Furthermore, another one liner code is displayed in Program 3 which needs to be added whenever there is an interaction in the application. Then the collected data will be stored in to local database (SQLite database which will be discussed in Section 5.4). Finally, the required data will be transferred to the server.

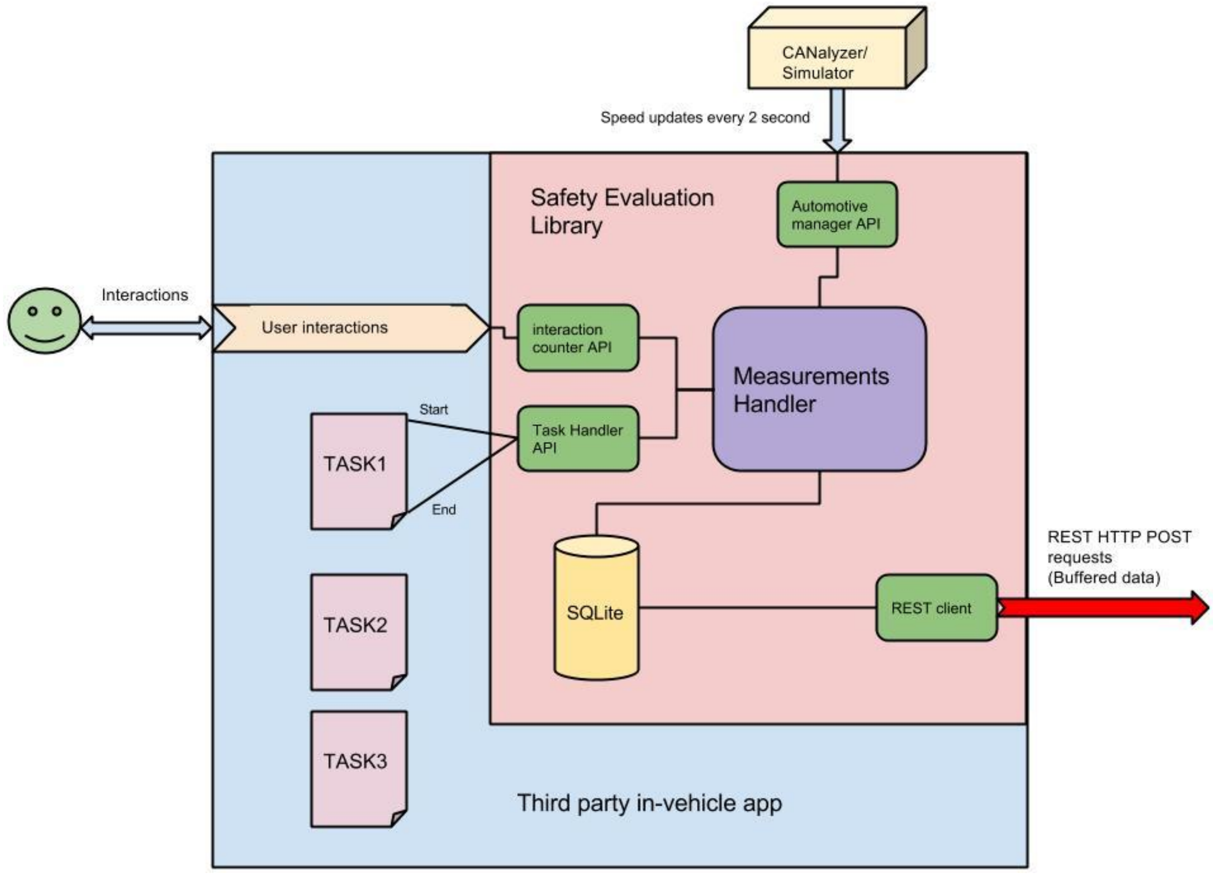


Figure 5. Architecture of the client Side

As it shown in Figure 5, safety evaluation library will be used by in-vehicle app developers. This library is responsible for collecting all in-vehicle application's information such as start and finish time of a task as well as the vehicle metrics such as speed at the same time. Developers of in-vehicle apps should use certain APIs to target certain tasks on their apps for safety analysis so that the library can detect the start and end time of the safety concerned tasks. Code snippet 1 and 2 show two one liners that need to be used by third-party developers when a task starts and ends. Furthermore, another API is provided by the library to detect user interactions with the app. Code snippet 3 shows another one liner code which needs to be added whenever there is an interaction in an application. The library also provides set of APIs to connect the app to a vehicle simulator to determine the vehicle's speed in 2 seconds intervals. Then all the needed data will be collected by measurements handler component which stores them into the library's local database (SQLite database which will be discussed in Section 5.4).

Finally, the required data will be buffered and transferred to the server using simple HTTP POST requests.

```
    TextView destinationField = (TextView)findViewById(R.id.destinationtext);
    destinationField.setOnClickListener(new View.OnClickListener() {

        @Override
        public void onClick(View v) {

            Measurement.startTask(getBaseContext(), 1);

            Measurement.countClick(getBaseContext(), 1);

            Intent enterDestination = new Intent(getBaseContext(), EnterDestinationActivity.class);
            startActivity(enterDestination);
            overridePendingTransition (R.anim.fade_in, R.anim.fade_out);

        }

    });

}
```

Program 1. One liner code when a task starts.

```
public void setRoute(String des){

    destination = des;

    webView.setWebViewClient(new WebViewClient(){

        public void onPageFinished(WebView view, String url)
        {
            super.onPageFinished(view, url);
            if (dialog != null && dialog.isShowing()){
                dialog.dismiss();
            }
            webView.loadUrl("javascript:setLocation('"+destination+"')");

            Measurement.endTask(getBaseContext(), 1);
        }
    });
}
```

Program 2. One liner code when a task ends.

```
    TextView destinationField = (TextView)findViewById(R.id.destinationtext);
    destinationField.setOnClickListener(new View.OnClickListener() {

        @Override
        public void onClick(View v) {

            Measurement.startTask(getBaseContext(), 1);

            Measurement.countClick(getBaseContext(), 1);

            Intent enterDestination = new Intent(getBaseContext(), EnterDestinationActivity.class);
            startActivity(enterDestination);
            overridePendingTransition (R.anim.fade_in, R.anim.fade_out);

        }

    });

}
```

Program 3. One liner code when there is an interaction.

5.3 Safety Evaluation Server

In order to transfer collected data from Android in-vehicle applications and vehicle to the server and then store them in the database, RESTful web service was used. The main advantages of using RESTful web service is that the server is going to be used by many different in-vehicle applications and the server can be updated regularly without needing to update the in-vehicle applications. This client server architecture will make the server side simpler and more scalable since the server is not concerned by the user's state. The connection to the server is stateless and the server does not need to store client context between requests. Furthermore the client cannot distinguish that it is connected to the end server or some intermediary server. This gives the room for improvement if there is going to be any load balancing solution implemented for the final product. Figure 6 illustrates various services and components that are included in the server side.

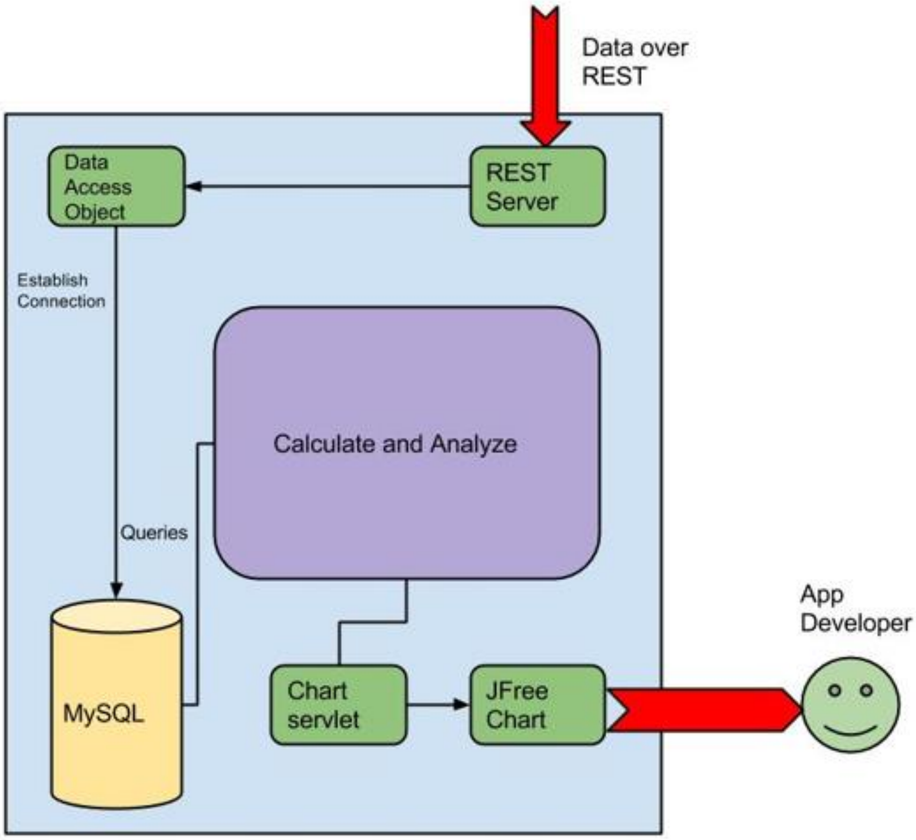


Figure 6. Architecture of the server side

After getting data from the client library over REST, the REST server will establish a connection with the server's MySQL database and stores the related data. Furthermore, data will be queried, calculated and analyzed by the server and ready to serve using the chart servlet that is responsible to request various charts from JFreeChart. At the end app developers or OEM are able to request these charts from the server to make their final optimization regarding safety issues.

5.4 Database Design

As it was discussed in Chapter 3, the collected data in the on-road method is the most accurate one in comparison with other measuring distraction methods since the information have been got from the real driving situation. However, the enlargement of the data in the database is one of the on-road method's disadvantages because some of those data that are not used in the final decision-making, is still in the database which takes a lot of times to analyse the huge amount of data. In order to solve the referred problem, two databases are used in this study: database in the client side and database in the server side. First all the information will be collected in the local database, then only the required data is transferred into the database in the server side for the final analysis.

After getting the data from the Android in-vehicle applications and the vehicle, the information will be stored in the local database in the client side. Regarding this, Android SQLite database was used in this thesis which is part of the safety evaluation library. SQLite is an Open Source database that is embedded into every Android device and using a SQLite database in Android does not require a setup procedure or administration of the database. Furthermore, the database is automatically managed by the Android platform. All the information from the in-vehicle applications and vehicles is collected and then transferred from each tables in the SQLite database to the server in 10 rows chunks.
After receiving the required data in the server, the data will be sent to the connected database to the server. MySQL database is used in this study to store both application's and vehicle's metrics in the server. Then, the data is ready to be used for the analysis by using a presentation tool.

5.5 Presentation

One of the most important part of this research project is to present the collected data to the OEMs and third-party developers for the safety analysis.

During this study, two presentation tools were used to present collected data for the better understanding of the behaviour of in-vehicle applications: Microsoft Excel 2013 and JFreeChart.
At the beginning of this study, it was decided to use Microsoft Excel software to show the results and their relationship since it is simple and easy to use and the information can be shown in different types of charts such as pie, column, line, bar, area, and scatter. Regarding this, MySQL database was connected to the Excel 2013 via MySQL connector. After that, it was possible to import the tables from the database using "DATA" tab in the ribbon of the Excel program. Finally, different kinds of charts could be made from the related data in the tables which makes the safety analysis significantly easier and more comprehensive.

However, using the Excel program to present the collected data was not so feasible in this study. The reason behind was that the database will be updated continuously with new information and in order to have the most updated charts, it is needed to import all the tables repeatedly in the Excel program and then making the charts all over again.

Therefore, it was essential to have a presentation tool that satisfies the fast updating factor.

After doing more research, JFreeChart was chosen to be used for the presentation part of this study. JFreeChart is a free java chart library that makes it easy to display charts in the applications. Since JFreeChart is connected to the database directly, it is possible to have different charts with the latest updated information using the related queries. Figure 7 is an example of JFreeChart which shows three different charts at the same time.

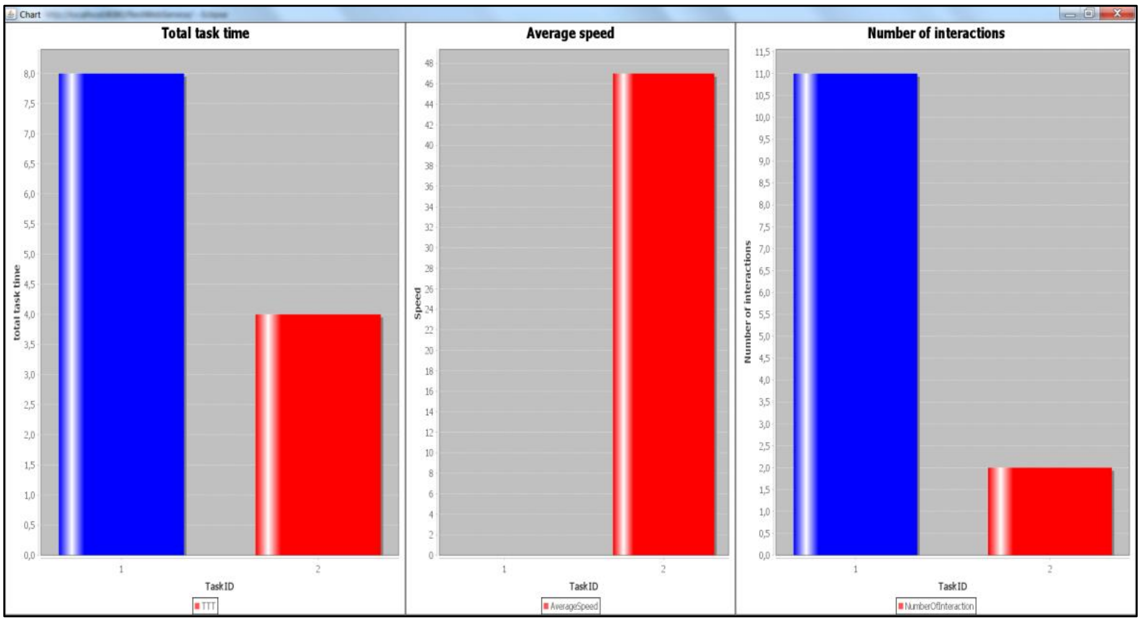


Figure 7. Different bar charts with the use of JFreeChart.

5.6 Automotive Grade Android simulator

As it was mentioned earlier, based on literature review, driver safety guidelines and standards, three vehicle’s metric were selected to be used in the framework that are related to the safety issue. These metrics were supposed to be got from the vehicle in the real driving situation. Nevertheless, at the time of this thesis, it was not possible to deploy the framework to be used in the real vehicle. Instead, it was decided to use Automotive Grade Android (AGA) simulator [Combitech and Swedspot, 2014] in order to get vehicle’s metrics.

AGA simulator is an open source software platform that enables developers to integrate their Android application with an in-vehicle infotainment system. Furthermore, AGA simulator provides an API to the vehicle, both to read data and to inject data. In other word, developers can use this simulator while they are developing their in-vehicle applications to:

- Make them vehicle-aware.
- Provide better interfaces based on context.
- Minimize distraction while driving.
- Integrate with other connected services.
- Get more insight into the vehicle's operation.

The instruction on how to get AGA simulator up and running within an Android applications can be found in the website [Combitech and Swedspot, 2014]. After connecting the simulator to the framework, the below window will be shown.

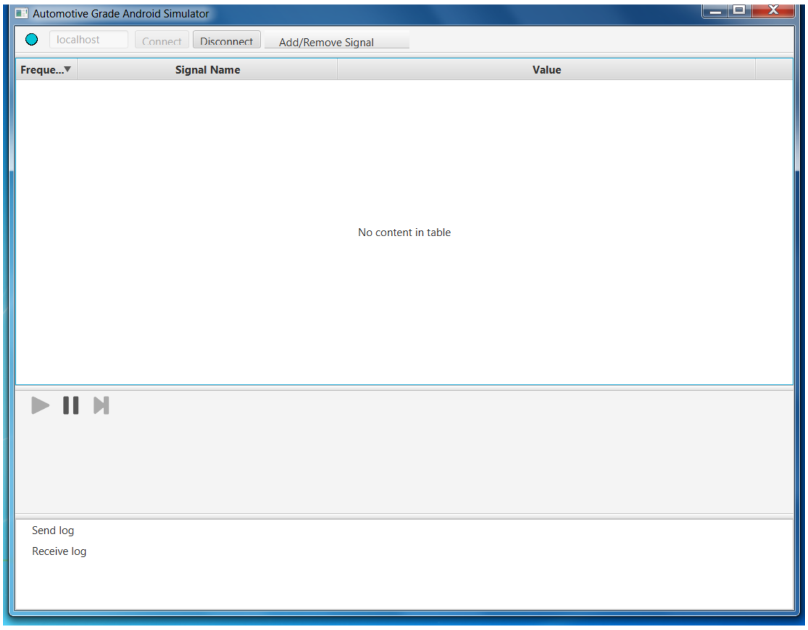


Figure 8. AGA simulator.

By pressing the “Add/Remove signal” button, different signals can be added and logged from database which consists of Fleet Management System Standard (FMS) signals. However, all three safety metrics that were discussed to be got from the vehicle are not included in FMS signals. Thus, the only vehicle metric that is used in the framework is vehicle speed which is shown in Figure 9.

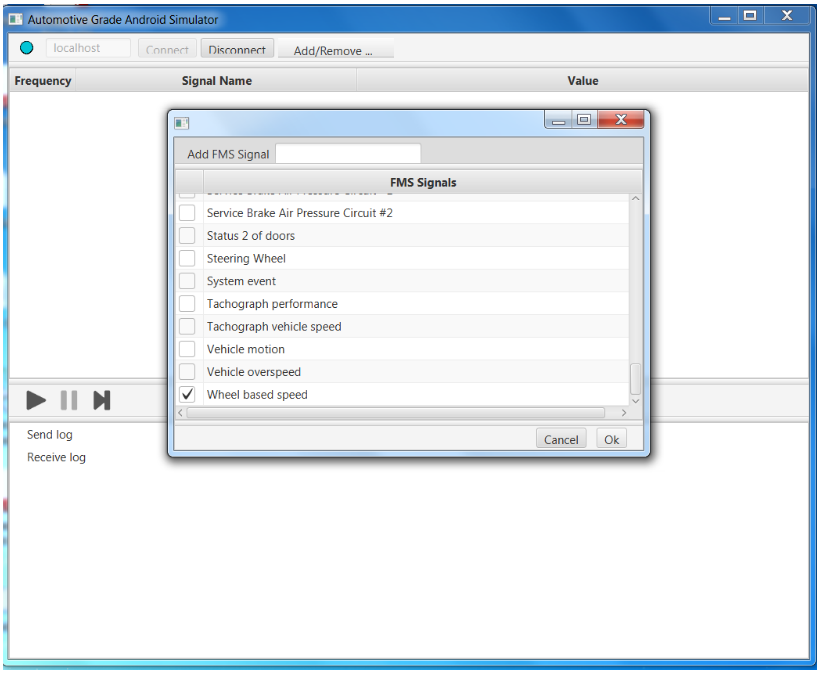


Figure 9. Different vehicle metrics from FMS database.

Then, the speed signal along with the slider will be shown in the window. By clicking the ► button it is possible to manipulate the slider to change the speed and send the signal through the framework (Figure 10).

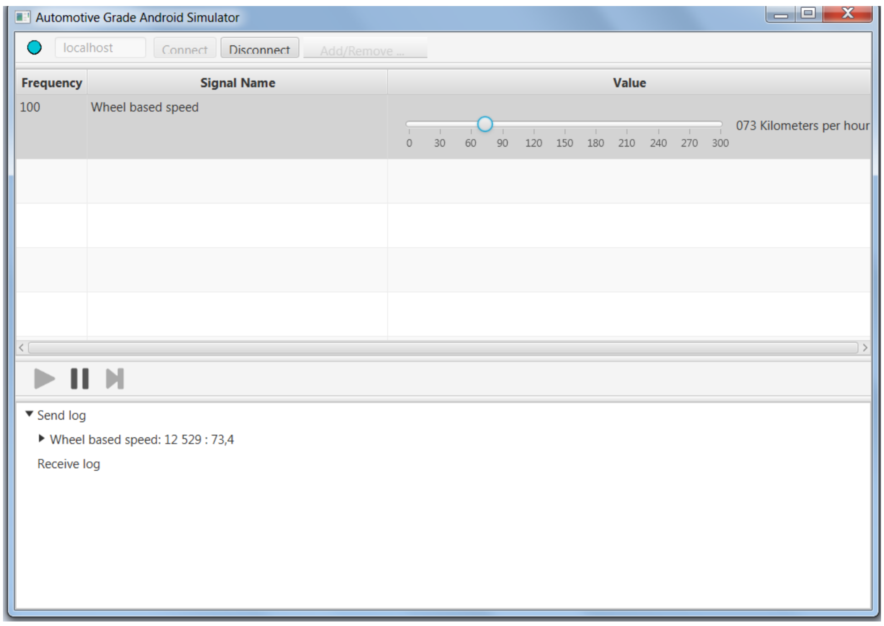


Figure 10. Sending the speed signal through the framework.

AGA API (Application Programming Interfaces) was used in the evaluation safety library to receive the speed signal.

5.7 Case Studies and Finding Analysis

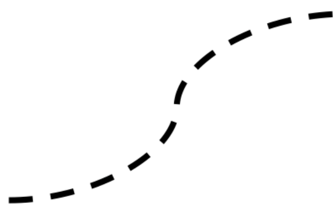
The goal of this section is to test the framework by two in-vehicle applications following by analysing the results.

5.7.1 Predicted Range Interval Next Generation Application

Overview. Predicted Range Interval Next Generation (PRING) is an in-vehicle application that predicts range intervals based on vehicle parameters. The main concept of PRING application is to be used when planning the route due to time and resource constraints. PRING will be implemented and deployed and work in a hybrid car, with a 7 inch in-vehicle screen. The PRING concept will be developed on Parrot's Devkit, running Android version 2.3.7.

To understand how the PRING application works a user story is explained as follows:

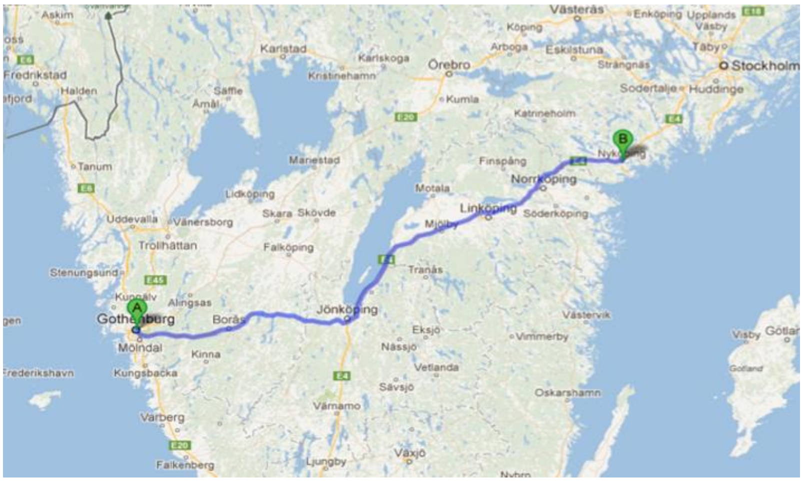
1. As a user I want to drive from Gothenburg to Stockholm



2. I enter Stokholm in the destination field
3. My hybrid car is set to Power Mode which consumes a lot of energy:

Pedal responsiveness – Power
Instrument panel light – Fully light
Haptic Pedal – Normal

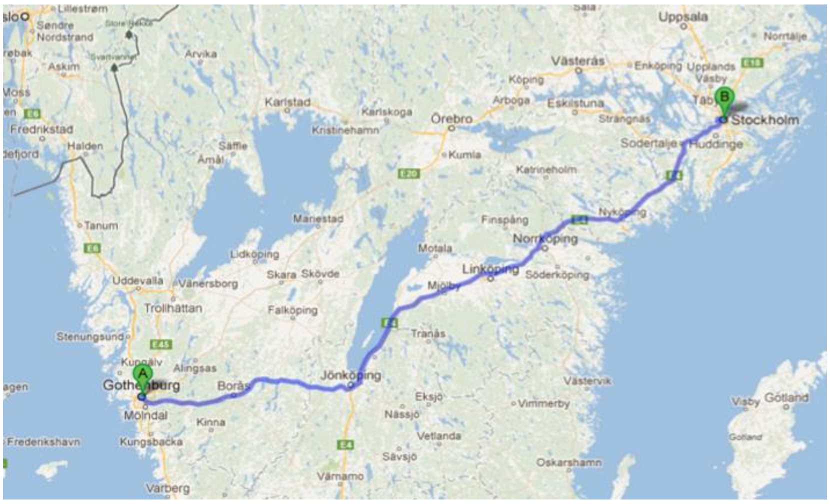
4. The Predicted Range Interval map will show that I will not make it to Stockholm



5. I will then change vehicle mode (or the app will do it automatically for me) to Pure Mode which consumes less energy than the Power Configuration mode:

Pedal responsiveness – Eco
Instrument panel light – Dark
Haptic pedal – Eco guide

6. The Predicted Range Interval map will show that I will make it to Stockholm



Regarding PRING interface, the Predicted Range Interval map is the first view that the user will experience, and also the view that will be the most viewable one. The user can also see the current vehicle mode all the time at the bottom left of the screen in the form of a touch button. When this button is touched the user is presented with a transparent view with the possibility to change vehicle mode.

Moreover, the user can also see the destination name all the time at the bottom right in the form of a touch button. When this button is touched the user can provide a new destination.

Aim of the study. The goal of using the framework for PRING application is to investigate the safety aspects of different tasks within the application and give the feedback to the developers for improvement.

Deployment. Table 3 shows two tasks that are defined in the application. First task is “Destination entry” and starts when the driver touches the direction button on the main view to enter a new destination and it ends when the desired destination is shown on the map. The second task is called “change mode” and starts when a driver presses the mode button on the bottom left and it ends when the driver chooses one of four vehicle modes from the list. For instance, in Figure 11 the vehicle mode is changed from hybrid to custom. Moreover, a threshold which is specified for the completion of the task is 12 seconds. It means that if a task takes longer than 12 seconds to be completed, this task will be specified as an uncompleted task since NHTSA guideline limits the total task time to maximum 12 seconds. However, this threshold can be changed by the OEMs.

ID	Task Name
T1	Destination entry
T2	Change mode

Table 3. List of tasks.

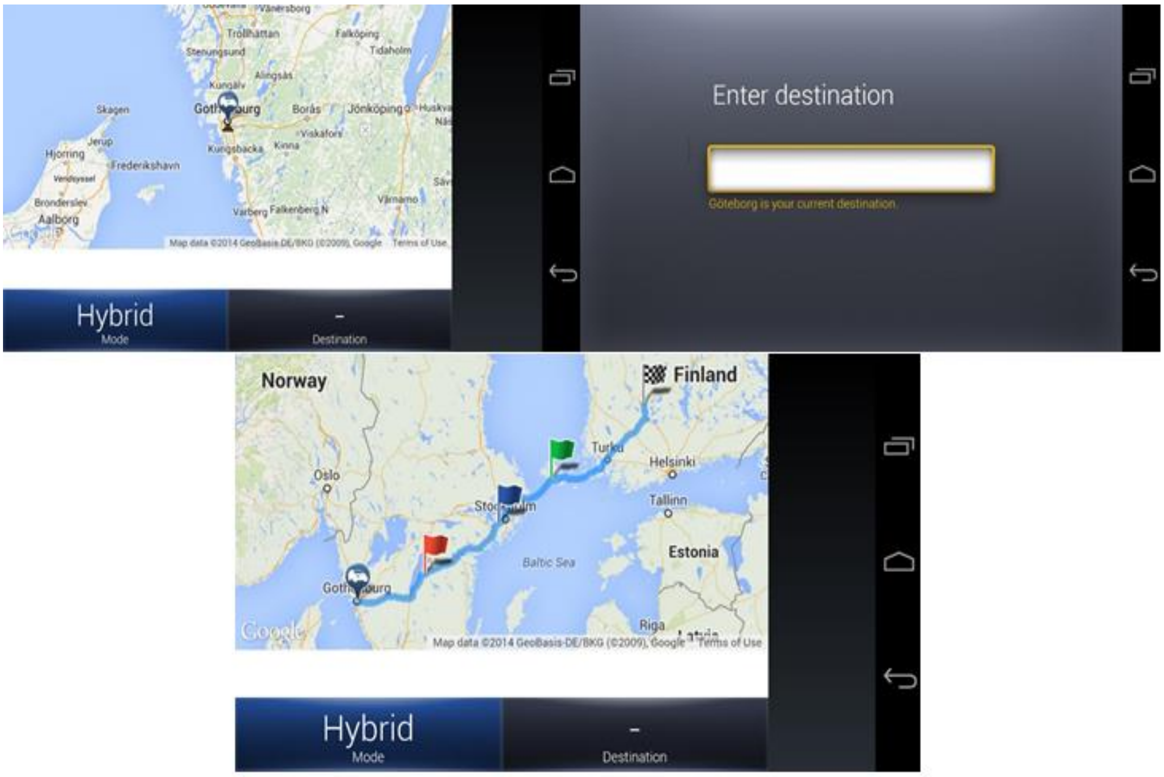


Figure 11. Task 1: obtaining the direction from PRING application.

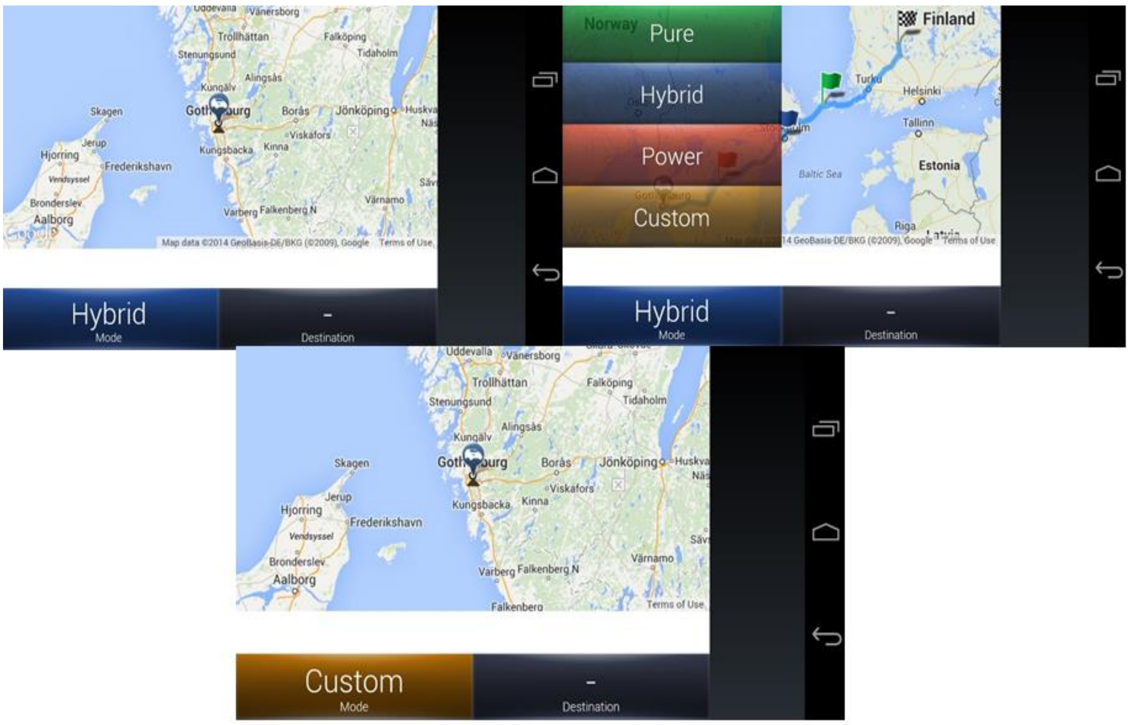


Figure 12. Task 2: changing the vehicle mode.

The safety analysis is presented in three sections, namely total task time, vehicle speed, the number of interactions.

Total task time. Table 4 shows the task durations of both T1 and T2. The highest total task time was recorded for T1 (destination entry) which is 7.5 seconds. Moreover, the task completion rate for T1 was 80% which shows that sometime it took more than 12 seconds for the driver to finish it and should be taken into consideration by the application's developers. On the other hand, T2 only took 3 seconds to be completed by the driver. In addition, the task completion rate of task 2 is 100% which indicates that it can be performed in a safe and simple manner by a driver.

Task ID	Total task time(s)
T1	7.8
T2	3

Table 4. Total task time.

Task ID	Task completion rate
T1	8
T2	10

Table 5. Task completion rate.

Vehicle Speed. Table 6 displays the average vehicle speed for each task. The result showed that when the driver performed "destination entry" task, notable reductions in vehicle speed were observed. This is reasonable because the driver wanted to reduce a car crash risk. Further analysis showed that there were greater variations in the vehicle speed for T1 rather than T2 which means that it is hard for the driver to maintain the car speed and perform the "entry destination" task simultaneously.

Task ID	Average speed(km/h)
T1	52
T2	60

Table 6. Average speed.

Number of interactions. Table 7 shows the number of interactions for both entry destination and change mode tasks. The former had the average number of interactions of 5 since the driver had to write at least the first two letters of the place to get the list of suggested destination and then choose one to get the direction. However, as it mentioned above, task completion rate for T1 is 80.5 percent which means that in some cases the driver started the task but either s/he could not finish it or the task took longer than 12 seconds to be finished. The most probable reason lies in the user interface. Therefore, the user interface should be improved to reduce the number of interactions which makes drivers to spend more time on driving task rather than look inside the vehicle. On the other hand, the average number of interactions and the task completion rate for change mode task are 2 and 100 percent respectively which shows that this task is quite easy and user friendly for the driver.

Task ID	Number of interactions
T1	5
T2	2

Table 7. Average number of interactions.

5.7.2 Messaging Application

Overview. The second application that is used as a case study in this thesis is Messaging application which was developed by two developers as a concept application in HiQ Company. This application provides a simple sending and receiving text messages in two modes: stand still and while driving. The main concept behind the messaging application is to make driving safer by making the contact list bigger in the driving mode or lock out some features such as typing texts and instead using default messages.

Aim of the study. The goal of using the framework for Messaging application is to evaluate the safety of the application when a drivers interacts with it in the real driving situation and then compares it to standstill situation when a driver can type a message.

Deployment. Table 8 shows two tasks from the application. The first one is "standstill mode messaging" and it starts when a driver chooses a contact from contact list and it ends when the send button is touched. The second task is "driving mode messaging" and it starts when one contact is selected from contact list in the driving mode and it is finished when the driver sends the default message to the contact person. Moreover, a threshold is specified for the completion of the task which is 12 seconds. It means that if a task takes longer than 12 seconds to be completed, this task will be specified as an uncompleted task since NHTSA guideline limits the total task time to maximum 12 seconds. However, this threshold can be changed by the OEMs. Figure 11 and 12 shows two tasks from Messaging application.

Task ID	Task Name
T1	standstill mode messaging
T2	driving mode messaging

Table 8. List of Tasks.

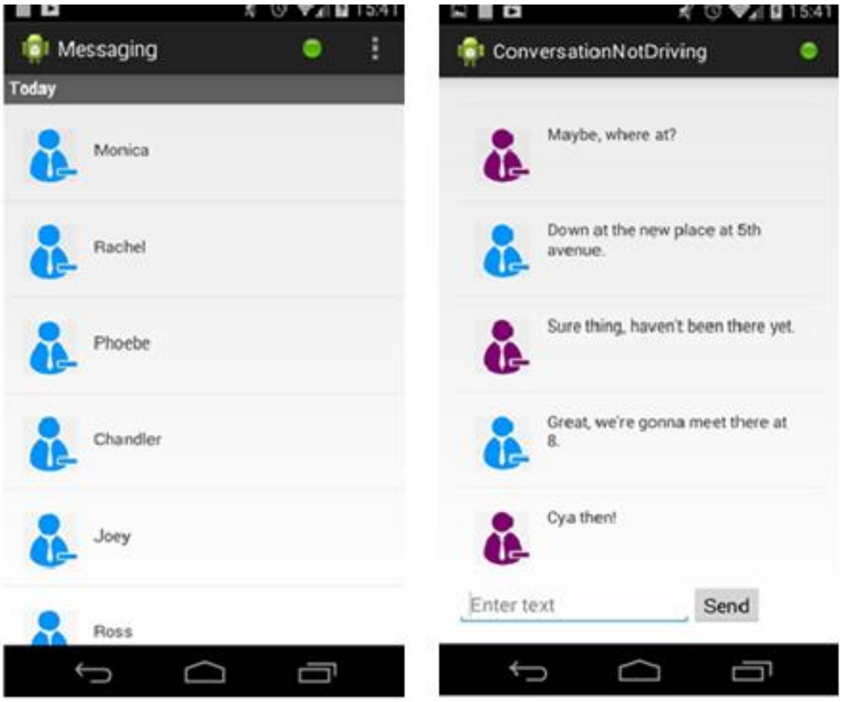


Figure 13. Task 1: sending a message in the stand-still mode.

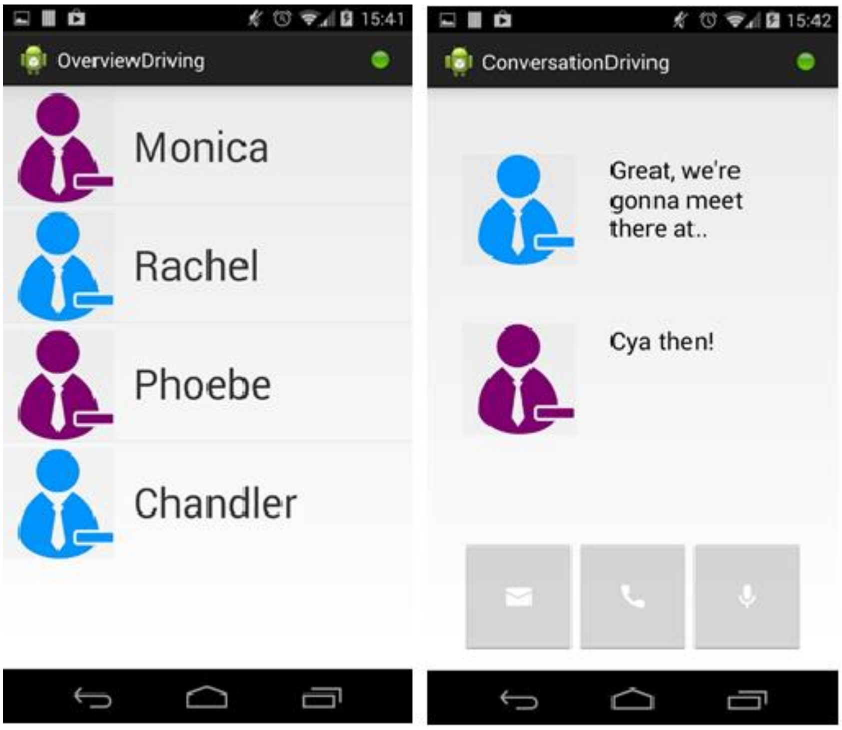


Figure 14. Task 2: sending a pre default message in driving mode.

The safety analysis is presented in three different sections including total task time, vehicle speed, and the number of interactions.

Total task time. Table 9 shows the task durations of both T1 and T2. In the standstill situation, it took almost 8 seconds for the driver to send three-word message. However, in the driving mode, the average task duration is 4 seconds since the driver were not allowed to type the message and just sent a pre default message. Furthermore, the driver does not have to spend a lot of time on looking inside the car which makes the driver concentrate more on the driving task and decreases a car crash risk. The completion task rate for T2 is also 100% which shows that the task is quite easy for the driver to complete in the driving situation.

Task ID	Total task time(s)
T1	8
T2	4

Table 9. Total task time.

Task ID	Task completion rate
T1	10
T2	10

Table 10. Task Completion rate.

Vehicle Speed. Table 11 displays the average vehicle speed for each task. The average speed for T1 is 0 km/h since this task was locked in the driving situation. However, the result showed that when the driver performed T2, there was no significant reduction in vehicle speed which means that it was easy for the driver to maintain the car speed and perform T2 at the same time.

Task ID	Average speed(km/h)
T1	0
T2	47

Table 11. Average speed.

Number of interactions. Table 12 displays number of interactions for both standstill and driving mode tasks. In the standstill mode, the average number of interactions is 11 since the driver wrote three-word message. On the other hand, the average number of interactions in the driving mode is 2 since the driver only can choose a contact and send the pre default messages.

Task ID	Number of interactions
T1	11
T2	2

Table 12. Number of interactions.

Using the evaluation framework shows that sending pre default massages in the driving situation instead of typing a text is a good way to increase the safety since drivers can spend less time on looking inside the car and then focus more on the driving task.

6 CONCLUSION AND FUTURE WORK

Driving is a complicated task which requires drivers to significantly focus and concentrate on it. Nevertheless, a lot of drivers engage in different activities such as eating, talking on the phone or texting a message while driving which can easily distract them and might lead to car crashes. This behavior is becoming more common since drivers and customers have a strong desire for the use of new technologies and functionalities which most of them are not designed to be used inside the vehicle in the driving situation. Therefore, a lot of research has been conducted to study about the driver distraction and its effect on the driving performance. Additionally, there are a number of methods and metrics for measuring distraction and evaluating the impact of interacting with in-vehicle technologies and applications on the driving performance regarding safety. The most proper method to use highly depends on what aspects of the driver distraction are being examined. However, naturalistic methods compared to other methods, are more realistic and valid since they collect data in the real driving situation.

The goal of the framework developed in this study is to assess in-vehicle applications and check how the applications behave regarding safety when a driver interacts with them in the real driving situation. Implementation was carried out in HiQ Company and continued as a fully functional system. Considering the evaluation of the framework, it was deployed and tested by two case study applications to find out how it can help third-party developers to get safety feedback from the application.

The results from the study indicate that the framework can increase the safety in the driver distraction area since it can help OEMs and third-party developers to understand how their applications behave in the real driving situation to improve and make them safer. Moreover, unlike the experimental methods such as simulators that are not very realistic, the developed framework in this study provides the accurate information about the safety implications of performing secondary visual-manual tasks since it collects the data in the real driving situation.

In addition, one of the problems of naturalistic studies is collecting a huge amount of data that is not related to the safety which makes the analysis quite challenging and time-consuming. However, the referred issue is solved by providing two databases in the framework. While the local database in the client side collects all the data from the vehicle and applications, only the required information is transferred to the database in the server side for the safety analysis. Therefore, it does not need to spend so much time on analysing the collected data.

Along with the main results which addressed the main objectives of this thesis, there are several other noteworthy findings. For instance, using the safety evaluation library is easy for developers which is one of the most important factors that should be considered during the development of the library.

As a recommendation for future work, the framework will be deployed in the real car and connected to the vehicle’s core system to get vehicle data. Considering the time constraint to get feedback from the developers that used the framework, an extended investigation is needed in order to consider different in-vehicle applications and make the use of the framework and especially safety evaluation library as simple as possible for the third-party developers. For instance, there is one idea that the developers just import the safety evaluation library without using any one liner codes and the library automatically identify first and end of tasks within the applications. Furthermore, more research on finding the safety metrics is beneficial to have more precise analysis of the behaviour of application in the driving environment.

REFERENCES

[Angell et al., 2006] Angell, L. S., Auflick, J., Austria, P. A., Kochhar, D. S., Tijerina, L., Biever, W., Diptiman, T., Hogsett, J. & Kiger, S. (2006). *Driver workload metrics task 2 final report* (No. HS-810 635).

[Alliance of Automobile Manufacturers, 2006] Alliance of Automobile Manufacturers. (2006). *Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems.* Washington, D.C. Alliance of Automobile Manufacturers,. Retrieved 11 27, 2014, from http://umich.edu/

[Apple, 2014] Apple. (2014). *Your iPod just called shotgun*. Retrieved December 2, 2014, from https://www.apple.com/ipod/car-integration/#mercedes

[Baumann et al., 2004] Baumann, M., Keinath, A., Krems, J. F., & Bengler, K. (2004). Evaluation of in-vehicle HMI using occlusion techniques: experimental results and practical implications. *35*(3), pp. 197-205.

[Beirness, 2002] Beirness, D. J., Simpson, H. M., & Desmond, K. (2002). *The Road Safety Monitor 2002: Risky Driving.* Ottawa, Ontario : Traffic Injury Research Foundation.

[Burnett et al., 2001] Burnett, G. E., & Porter, M. J. (2001). Ubiquitous computing within cars: designing controls for non-visual use. *International Journal of Human-Computer Studies, 55*(4), 521-531.

[Burns et al., 2010] Burns, P., Harbluk, J., Foley, J. P., & Angell, L. (2010). The Importance of Task Duration and Related Measures in Assessing the Distraction Potential of In-Vehicle Tasks.

[Campbell et al., 1998] Campbell, J. L., Carney, C., & Kantowitz, B. H. (1998). *Human factors design guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations (CVO).*

[Chiang et al., 2001] Chiang, D. P., Brooks, A. M., & Weir, D. H. (2001). An Experimental Study of Destination Entry with an Example Automobile Navigation System. pp. 113-123.

[Christopher et al., 2001] Christopher, N., Friedman, D., & Green, P. (2001). *Cell phone ring suppression and HUD Caller ID: Effectiveness in reducing momentary driver distraction under varying workload levels.* NASA STI/Recon Technical Report .

[Combitech and Swedspot, 2014] Combitech, & Swedspot. (2014). *AUTOMOTIVE GRADE ANDROID*. (Combitech and Swedspot) Retrieved 01 08, 2015, from https://developer.lindholmen.se/redmine/projects/aga

[Commission of the European Communities, 2005] Commission of the European Communities. (2005). *European Statement of Principles on the Design of Human*

Machine Interaction (ESoP 2005) Draft. Retrieved 11 29, 2014, from http://www.esafetysupport.info/download/working_groups/esop_hmi_statement.pdf

[Commission of the European Communities, 1999] Commission of the European communities. (1999). *Statement of principles on human machine interface for in-vehicle information and communication systems.* Brussels.

[Dingus et al., 1995] Dingus, T. A., Fleischman, R., Mollenhauer, M., Manakkal, N., Jahns, S., Hülse, M., & McGehee, D. (1995). *Travtek Evaluation Task C3 - Camera Car Study.*

[Crandall and Chaparro, 2012] Crandall, J. M., & Chaparro, A. (2012). Driver distraction: Effects of text entry methods on driving performance. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 56(1), 1693-1697.

[Eost and Flyte, 1998] Eost, C., & Flyte , M. G. (1998). An investigation into the use of the car as a mobile office. *29*(5), 383-388.

[ERTRAC, 2011] ERTRAC. (2011). *Roadmap on Safe Road Transport.* European Road Transport Research Advisory Council (ERTRAC) Working Group Road Transport Safety and Security.

[eSafety Forum, 2004] eSafety Forum. (2004). *Recommendations from the eSafety-HMI Working Group.*

[Feenstra et al., 2008] Feenstra, P. J., Hogema, J. H., & Vonk, T. (2008, June). Traffic safety effects of navigation systems. 1203 - 1208.

[Foley, 2000] Foley, J. (2000). *SAE Recommended Practice Navigation and Route Guidance Function Accessibility While Driving (SAE 2364)* .

[Foley, 2008] Foley, J. P. (2008). Now You See It, Now You Don't: Visual Occlusion as a Surrogate Distraction Measurement Technique. In M. A. Regan, J. D. Lee, & K. L. Young (Eds.). CRC Press.

[Funkhouser and Chrysler, 2007] Funkhouser, D., & Chrysler, S. T. (2007). *Assessing Driver Distraction Due to In-vehicle Video Systems Through Field Testing at the Pecos Research and Testing Center.* Southwest Region University Transportation Center, Texas Transportation Institute, Texas A&M University System.

[Green, 1997] Green, P. (1997, June 19). Potential safety impacts of automotive navigation systems.

[Green and Williams, 1993] Green, P., Hoekstra, E., & Williams, M. (1993). *On-the-Road Test of Drivers Road Tests of Driver Information System Interfaces: Examination of a Road Guidance System and a Car Phone.* The University of Michigan.

[Green et al., 1995] Green, P., Levison, W., Paelke, G., & Serafin, C. (1995). *Preliminary human factors guidelines for driver information systems (Technical Report*

FHWA-RD-94-087). McLean, US Department of Transportation, Federal Highway Administration.

[Haigney and Westerman, 2001] Haigney, D., & Westerman, S. J. (2001). Mobile phone use and driving: a critical review of research methodolog. *44*(2), 132-143.

[Harbluk et al., 2002] Harbluk, J. L., Noy, L. Y., & Eizenman, M. (2002). *The impact of cognitive distraction on driver visual behaviour and vehicle control (No. TP# 13889 E).* Transport Canada Publication. Retrieved from http://www.collectionscanada.gc.ca/webarchives/20060212011308/http://www.tc.gc.ca/roadsafety/tp/tp13889/pdf/tp13889es.pdf

[Hevner et al., 2004] Hevner, A., March, S. M., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *28*(1), pp. 75-105.

[Horrey et al., 2003] Horrey, W. J., Wickens, C. D., & Alexander, A. L. (2003). The effects of head-up display clutter and in-vehicle display separation on concurrent driving performance. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 47(16),* 1880-1884.

[Humanist, 2009] Humanist. (2009). *the expansion of ESoP in the framework of the eSafety initiative.* Retrieved from http://www.noehumanist.org/documents/Deliverables/TF4/4-3-HUMANIST_INR_BAS_TRL_deliverable_VA1.pdf

[International Organization for Standardization, 2002] International Organization for Standardization. (2002). *Road vehicles — Ergonomic aspects of transport information and control systems — Dialogue management principles and compliance procedures (ISO Standard 15005:2002).* Geneva, Switzerland.

[International Organization for Standardization, 2002] International Organization for Standardization. (2002). *Road vehicles — Measurement of driver visual behavior with respect to transport information and control systems — Part 1: Defi nitions and parameters (ISO Standard 15007-1: 2002).* Geneva, Switzerland.

[International Organization for Standardization, 2007] International Organization for Standardization. (2007). *Road vehicles — Ergonomic aspects of transport information and control systems — Occlusion method to assess visual distraction due to the use of in-vehicle information and communication systems (ISO Standard16673: 2007).* Geneva, Switzerland.

[International Organization for Standardization, 2013] International Organization for Standardization, (2013). *Measuring The Information Society.* International Telecommunication Union. Retrieved 11 12, 2014, from http://www.itu.int/dms_pub/itu-d/opb/ind/D-IND-ICTOI-2013-SUM-PDF-E.pdf

[Ito, 2001] Ito, H., Uno, H., Atsumi, B., & Akamatsu, M. (2001). Visual distraction while driving: Trends in Research and standardisation. *25*(2), pp. 20-28.

[Jancke et al., 1994] Jancke, L., Musial, F., Vogt, J., & Kalveram, K. T. (1994). Monitoring radio programs and time of day affect simulated car driving performance. *79*(1), 484-486.

[Janitzek et al., 2010] Janitzek, T., Jamson, S., & Eksler, V. (2010). *Study on the regulatory situation in the member states regarding brought-in (i.e. nomadic) devices and their use in vehicles.* European Union.

[Jenness et al., 2002] Jenness, J. W., Lattanzio, R. J., O'Toole, M., & Taylor, N. (2002). Voice-activated dialing or eating a cheeseburger: Which is more distracting during simulated driving? *46*(4), 592-596.

[Johansson et al., 2004] Johansson, E., Engström, J., Cherri, C., Nodari, E., Tofferri, A., Schindhelm, R., & Gelau, C. (2004) *Review of existing techniques and metrics for IVIS and ADAS Assesment.* VTEC, CRF, BASt. Available at:http://www.aide-eu.org/res_sp2.html.

[Kircher et al., 2004] Kircher, A., Vogel, K., Törnros, J., Bolling, A., Nilsson, L., Patten, C., . . . Ceci, R. (2004). *Mobile telephone simulator study.* Linkoping: Swedish National Road and Transport Research Institute.

[Kircher et al., 2011] Kircher, K., Patten, C., & Ahlström, C. (2011). *Mobile telephones and other communication devices and their impact on traffic safety.* Swedish national Road and Transport Research Institute. VTI Report A, 729.

[Klauer et al., 2006] Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J., & Ramsey, D. (2006). *The impact of driver inattention on near-crash/crash risk: an analysis using the 100-car naturalistic driving study data.* National Highway Traffic Safety Administration.

[Klauer et al., 2014] Klauer, S. G., Guo, F., Simons-Morton, B. G., Ouimet, M. C., & Lee, S. E. (2014). Distracted Driving and Risk of Road Crashes among Novice and Experienced Drivers. *The New England Journal of Medicin*, 54-59.

[Lam, 2002] Lam, L. T. (2002). Distractions and the risk of car crash injury: The effect of drivers' age. *33*(3), 414-419.

[Lee, 2001] Lee, J. D., Caven , B., Haake, S., & Brown, T. L. (2001). Speech-based Interaction with In-vehicle Computers: The Effect of Speech-based E-mail on Drivers' Attention to the Roadway. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *43*(4), pp. 631-640.

[Lissy et al., 2000] Lissy, K. S., Cohen, J. T., Park, M. Y., & Graham, J. D. (2000). *Cellular Phone Use While Driving: Risks and Benefits.*

[Marrkulla and Engstroem, 2006] Marrkulla, G., & Engstroem, J. (2006). A Steering Wheel Reversal Rate Metric for Assessing Effects of Visual and Cognitive Secondary Task Load. pp. 8-12.

[Martens and Winsum, 1999] Martens, M. H., & Winsum, W. V. (1999). Measuring distraction: the peripheral detection task. *TNO Human Factors*.

[Mccartt et al., 2006] Mccartt, A. T., Hellinga, L. A., & Bratiman, K. A. (2006). Cell phones and driving: review of research. *7*(2), 89-106.

[Nakamura, 2004] Nakamura, Y. (2004). *JAMA guideline for in-vehicle display systems.* Brussels: Convergence Technical Paper.

[NHTSA, 2010] NHTSA. (2010). *Traffic Safety Facts, Research Note: Distracted Driving 2009.* National Highway Traffic Safety Administration.

[NHTSA, 2012] NHTSA. (2012). *Visual-Manual NHTSA Driver Distraction Guidelines For In-Vehicle Electronic Devices.* Department of transportation. National Highway Traffic Safety Administration.

[Pattern et al., 2004] Patten, C. J. D., Kircher, A., Östlund, J. & Nilsson, L. (2004) *Using mobile telephones: Cognitive Workload and Attention Resource Allocation.* Accident Analysis and Prevention 36(3), 341-350

[Ranney et al., 2001] Ranney, T. A., Mazzae, E., Garrott, R., & Goodman, M. J. (2001). NHTSA Driver Distraction Research: Past, Present, and Future.

[Reed and Green, 1999] Reed, M. P., & Green, P. A. (1999). Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task. *42*(8), pp. 1015-1037.

[Reed and Robbins, 2008] Reed, N., & Robbins, R. (2008). *The Effect Of Text Messaging On Driver Behavior: A Simulator Study.* Published Project Report.

[Regan et al., 2001-5] Regan, M., Oxley, J., Godley, S., & Tingvall, C. (2001-5). *Intelligent Transport Systems: Safety and Human Factors Issues.*

[Salvucci et al., 2007] Salvucci, D. D., Markley, D., Zuber, M., & Brumby, D. P. (2007). iPod Distraction: Effects of Portable Music-Player Use on Driver Performance. 243-250.

[Sasanouchi et al., 2005] Sasanouchi, K., Ishiai, Y., Tanaka, T., Yukawa, J., & Hu, A. (2005). Development of the HMI system that improves the safety and operational convenience by the combination of steering wheel switch and head up display (No. 2005-01-0438). SAE Technical Paper.

[Schindhelm et al., 2004] Schindhelm, R., Gelau, C., Keinath, A., Bengler, K., Kussmann, H., Kompfner, P. & Martinetto, M. (2004). *Report on the review of the available guidelines and standards.* Technischer Bericht IST-1-507674-IP.

[Srinivasan and Jovanis, 1997] Srinivasan, R., & Jovanis, P. P. (1997). Effect of in-vehicle route guidance systems on driver workload and choice of vehicle speed: Findings from a driving simulator experiment. 97-114.

[Stuttus et al., 2001] Stutts, J. C., Reinfurt, D. W., Staplin, L., & Rodgman,, E. A. (2001). *The role of driver distraction in traffic crashes.* Report prepared for AAA Foundation for Traffic.

[Stuttus et al., 2003] Stutts, J., Feaganes, J., Rodgman, E., Hamlett, C., Meadows, T., Reinfurt, D. & Staplin, L. (2003). *Distractions in Everyday Driving.* Washington,, DC: AAA Foundation for Traffic Safety.

[Tasca, 2005] Tasca, L. (2005). Driver distraction: towards a working definition. Toronto, Canada: In International Conference on Distracted Driving.

[Tchankue et al., 2011] Tchankue, P., Wesson, J., & Vogts, D. (2011). The impact of an adaptive user interface on reducing driver distraction. 87-94.

[Tijerina, 2000] Tijerina, L., Johnston, S., Parmer, E., & Winterbottom, M. D. (2000). *driver Distraction Wireless telecommunications and Route Guidance Systems.* National Highway Traffic Safety Administration.

[Tijerina et al., 1998] Tijerina, L., Parmer, E., & Goodman, M. J. (1998). Driver workload assessment of route guidance system destination entry while driving: A test track study.

[Treat, 1986] Treat, J. R. (1980). A study of pre-crash factors involved in traffic accidents. *10*(11), pp. 1-35.

[Tsimhoni et al., 2004] Tsimhoni, O., Smith, D., & Green, P. (2004). Address entry while driving: Speech recognition versus a touch-screen keyboard. *46*(4), 600-61.

[White et al., 2008] White, K. M., Walsh, S. P., Hyde, M. K., & Watson , B. C. (2008). Dialling and Driving: Factors Influencing Intentions to Use a Mobile. *40*(6), pp. 1893-1900.

[World Health Organization, 2011] World Health Organization. (2011). *Mobile phone use: a growing problem of driver distraction.* Retrieved 11 12, 2014, from http://www.who.int/violence_injury_prevention/publications/road_traffic/distracted_driving_en.pdf

[Östlund et al., 2005] Östlund, J., Engström, J. & Johansson, E. (2005). Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *8*(2), 97-120.